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NEW
TEXT-BOOK
OF
GEOLOGY.

DESIGNED
FOR SCHOOLS AND ACADEMIES

BY
JAMES D. DANA, LL.D.

OF THE BUREAU OF GEOLOGY, "A SYSTEM OF GEOLOGY," OF THE
U. S. GEOLOGICAL SURVEY, "A SYSTEM OF GEOLOGY," OF THE
U. S. GEOLOGICAL SURVEY, "A SYSTEM OF GEOLOGY," OF THE
U. S. GEOLOGICAL SURVEY, "A SYSTEM OF GEOLOGY," OF THE

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NEW
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OF
G E O L O G Y.

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BY
JAMES D. DANA, LL.D.,
AUTHOR OF "A MANUAL OF GEOLOGY," "A SYSTEM OF MINERALOGY," OF REPORTS
OF WILKES'S EXPLORING EXPEDITION ON GEOLOGY, ZOÖPHYTES, AND
CRUSTACEA, "CORALS AND CORAL ISLANDS," ETC.

Fourth Edition,
REVISED AND ENLARGED.

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WILLIAM IVISON
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PREFACE.

IN preparing this Text-book of Geology, the general plan of my Manual has been retained. The science is not made a dry account of rocks and their fossils, but a history of the earth's continents, seas, strata, mountains, climates, and living races; and this history is illustrated, so far as the case admits, by means of American facts, without, however, overlooking those of other continents, and especially of Great Britain and Europe.

In this FOURTH EDITION, fifty pages have been added to the size of the work, in order to render the explanations simpler and more complete, and to give also a fuller account of the kinds of life which contribute to rock-making, of the geographical distribution of marine species, and of the depths of the seas. Each of these topics is illustrated by new cuts, and the last by a general map showing the depth of the Atlantic and Pacific oceans by bathymetric lines, based mainly on that of Mr. H. N. Moseley, of the Challenger expedition. The map of the vicinity of Naples is from Murray's Handbook.

No glossary of scientific terms is inserted, because the volume is throughout a glossary, or a book of explanations of such terms, and it is only necessary to refer to the Index to find where the explanations are given.

The teacher of Geology, and the student who would extend his inquiries beyond his study or recitation-room, is referred to the Manual for fuller explanations of all points that come under discussion in the Text-book, — including a more complete survey of the rock-formations of America and other parts of the world, with many sections and details of local geology, — a much more copious exhibition of the ancient life of the several epochs and periods and of the principles deduced from the succession of living species on the globe, — a more thorough elucidation of the departments of Physiographic and Dynamical Geology, — a chapter on the Mosaic Cosmogony, — a large number of additional illustrations, with references to authorities and personal acknowledgments, besides a general chart of the world.

The Text-book departs from the Manual in introducing the subject of Dynamical Geology before that of Historical Geology. This order has the advantage of supplying the student early in the course with a knowledge of the forces and operations in nature by which geological progress has gone forward. It has, at the same time, its disadvantages, inasmuch as the facts about the earth's strata must be

learned before the questions as to methods of formation can be fully appreciated. These difficulties are so great as regards the subject of mountain-making, that the study of Chapter VI., under Dynamical Geology had better be deferred until that of the Historical Geology is completed.

NEW HAVEN, CONN., September 1, 1883.

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INTRODUCTION

The Science of Geology. — Beneath the soil and waters of the earth's surface there is everywhere a basement of rocks. The rocky bluffs forming the sides of many valleys, the ledges about the tops of hills and mountains, and the cliffs along sea-shores, are portions of this basement exposed to view. Geology is the science that studies these rocks, not merely to learn about ore-beds, coal, and building materials, but primarily to gather from them facts about the earth's history, — the history of its rocks, features, and life. It is an outdoor science, and out of doors are found the best instruction-places for pupils and teacher.

In most of the rocky bluffs over the country the rocks lie in successive beds. The beds differ in thickness and in other ways. They may be all sandstone, and show the grains of sand distinctly under a pocket-lens. One or more of the beds may contain pebbles, smoothly worn pebbles with sand, the material of a gravel bed; another may be a slaty layer, so soft and fine-grained that if ground up and mixed with water it will make mud, — suggesting that it might have been formed out of mud. Should it be inferred, after examining such a bluff, that the beds were once real sand-beds, gravel-beds, mud-beds, which in some way were spread out in succession, and finally became hardened, it would be a right geological conclusion.

But the questions would arise: How were the pebbles rounded? How were the mud, sand, and gravel distributed in beds? Whence the sand, pebbles, and mud? At the foot of such a bluff there commonly lie heaps of loose sand and stones derived from the bluff. The rains, frost, and other causes keep wearing its surface, dropping grains and tumbling down fragments; and thus the heaps of *débris* are formed. If a stream runs by the base of such a bluff, the water when in rapid flow will wear it and carry off the material, grinding and rounding the fallen fragments. If the bluff stands on a seashore, the waves will beat against its exposed front, and aid other destroying agencies in the work of reducing it to sand, stones, and mud for distribution off the shore and up the beach.

All over the world the exposed rocks of hills, mountains, and plains are undergoing wear and decay, and becoming reduced to earth and coarser loose material. And if the whole world is thus engaged, and has always been at this work since rocks were first exposed to the action of the air and waters, there ought to have been at all times material enough for the soil and the rocky beds of all periods in the history.

Along the sides of a river-valley may often be seen beds of unsolidified sands and gravel, with sometimes clay, constituting low bluffs. These bluffs may be similar in the material of the beds to the rocky bluff alluded to, and the absence of consolidation may be the chief difference. Up or down the valley evidence may usually be found that such beds of loose material are much like deposits now made by the stream at high flood-level; that the waters where rapid are always making and rounding pebbles, and in flood-times are carrying down stream the ground-up material for deposition below. If such beds of gravel and sand are at too high levels to be made by modern floods, they are sure to be within the range of some greater flood of past geological time. Along a sea-

shore there are often similar bluffs which the sea has made; and great sand-flats off the coast, formed from sand and pebbles drifted by the sea-currents and waves; and rivers carry to the ocean a great amount of sediment to add to the marine deposits. The inference from the facts that the hard rocks are only consolidated deposits, and that they were spread out in beds in the same ways that beds are now formed along or off seashores, in river valleys, and about lakes, is right according to the fullest evidence from geological investigation. Nine tenths of the rocks studied by the geologist are water-made rocks, and nearly all the older water-made kinds are of marine origin.

Rocky bluffs often consist in part or wholly of beds of limestone. At the Bermudas, about Florida, and in other warm seas, the process of making limestones out of shells and corals can be studied; for the process is now going on as in ancient time.

The beds of a bluff may contain shells, corals, bones, or plant-remains,—fossils, as they are called, from the Latin word *fossilis*, signifying *dug up*. Such a discovery opens up a new subject. The shells or bones could not have got there except when the layer containing them was forming. They are like the shells in the mud or sand of existing sea-bottoms or sand-beaches. If they turn out to be marine fossils, the bed is of marine origin. But another lesson is taught; for the fossils make known what species were living in the seas when the bed was made. In a bed higher up in the series the fossils may be different in kind, showing that when that bed was in progress the old species had gone and new kinds had come in. In this way geology has learned much with regard to the life that existed on the globe when each of the successive rocks was made. Taking the whole geological series of rocks together from the bottom to the top,—the maximum thickness of which is over twenty-five miles,—it is found that new kinds continue to appear, and the old

to disappear, on passing up from one level to another. Thus a history of the life of the globe, from the simplest forms of the early rocks to mammals and man, has been to some extent made out.

From the above explanations it is obvious that several great subjects are treated under Geology. One is the structure of the globe, or the arrangement and characteristics of the rocks. A second is the historical succession in the formation of the rocks. A third is the historical succession in the life of the globe. A fourth is the *origin* of the beds of rock in the earth's structure; for the rocks that were made in the deep ocean, or in shallow oceans, or along sea-beaches, or in lakes, or in river-valleys, and so on, will bear some peculiarities in structure or fossils that will betray their origin.

Further, rocks over large areas have often been raised or pushed out of their original positions and made into mountains; and the times of these disturbances and the origin of the mountains are other subjects for geological study. And such upturned rocks have sometimes become crystallized, or converted into marble, granite, mica schist, and the like; and this is another of its topics.

Over the earth's surface the valleys and deep cañons have been made by rivers and their tributaries. And this work of the waters is one part of that of rock-making; for here the waters have derived much of their material. Water has worked also in the state of glaciers and icebergs.

Again, in many regions the earth's crust has been deeply fractured. Sometimes mineral veins have formed in the fissures. Often melted rock, from unknown depths, has come to the surface and spread widely over it, thus adding fire-made or igneous rocks to the water-made. Occasionally volcanoes have formed over the larger fissures; and in a few places geyser-regions, like that of the Yellowstone Park, have been left as the later work of the lingering fires.

The above are the more prominent subjects in Geology.

Forces of past and present time the same.—The preceding review teaches that the physical forces now in action have been the same, and under the same laws, through all past time. Whether those of the waters, the winds, heat, cohesion, or of whatever kind, they have produced results through the ages like those observed about us, with little difference except from greater intensity of action in early geological time. To existing nature, therefore, we safely go for the means of interpreting the geological records.

Subdivisions of the Science.—The *four* principal branches of the science are —

1. **Physiographic Geology**, — treating of the earth's physical features; that is, of the system in the exterior features of the earth. This department properly includes, also, the system of movements in the water and atmosphere, and the system in the earth's climates, and in the other physical agencies or conditions of the sphere.

2. **Structural Geology**, — treating of the rocks of the globe, their kinds, structure, arrangement in beds, and various conditions or modes of occurrence.

3. **Historical Geology**, — treating of the successive events in the history of the rocks, and of the continents, oceans, mountains, valleys, sea-limits, climates, and life.

4. **Dynamical Geology**, — treating of the causes, or the methods, by which all the earth's changes were brought about, including the making of continents, of ocean-basins, of rocks, of mountains, of valleys, the causes of all variations in climate, and of all changes in the earth's features, and in its living species as far as open to investigation. The word *dynamical* is from the Greek *δύναμις*, *power* or *force*.

PART I.

PHYSIOGRAPHIC GEOLOGY.

UNDER the department of Physiographic Geology only a brief and partial review is here made of the general features of the earth's surface.

THE EARTH'S FEATURES.

1. General Characteristics.

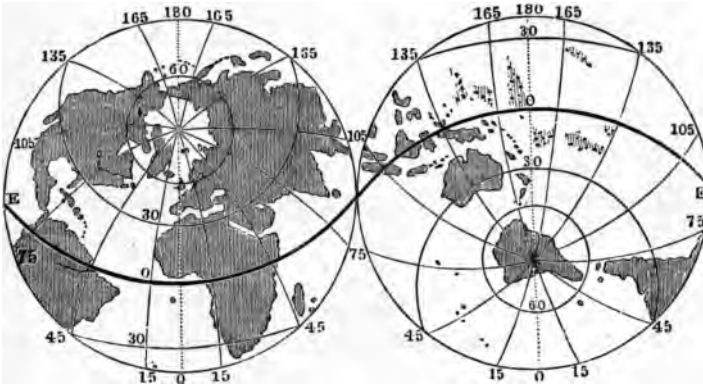
1. Size and form. — The earth has a circumference of about 25,000 (24,899) miles. Its form is that of a sphere flattened at the poles, the equatorial diameter (7,926 miles) being about $26\frac{1}{2}$ miles greater than the polar.

2. Oceanic basin and continental plateaus. — About *eight elevenths* of the earth's surface, or 144,000,000 of square miles, are depressed below the rest, and occupied by salt water. This sunken part of the crust is called the *oceanic basin*, and the large areas of land between, the *continents* or *continental plateaus*. The area of the continents is about 50,000,000 of square miles; and that of the islands, 2,900,000.

3. Subdivisions and relative positions of the oceanic basin and continental plateaus. — Nearly *three fourths* of the area of the continental plateaus are situated in the northern hemisphere, and very nearly *three fifths* of the oceanic basin in the southern hemisphere. The dry land, as shown in the following figure, may be said to be clustered about the North Pole, and to stretch southward in *two* masses, an *Oriental*, includ-

ing Europe, Asia, Africa, and Australasia, and an *Occidental*, including North and South America. The ocean is gathered in a similar manner about the South Pole, and extends north-

Fig. 1.



ward in *two* broad areas separating the Occident and Orient, namely, the Atlantic and Pacific Oceans, and also in a *third*, the Indian Ocean, separating the *southern prolongations* of the Orient, namely, Africa and Australasia.

The Orient is made, by this means, to have *two* southern prolongations, while the Occident, or America, has but one. This double feature of the Orient accords with its great breadth; for it averages 6,000 miles from east to west, which is far *more than twice* the mean breadth of the Occident (2,200 miles). See the following map.

The inequality of the two continental masses has its parallel in the inequality of the Pacific and Atlantic Oceans; for the former (6,000 miles broad) is more than double the average breadth of the latter (2,800 miles). Thus, *there is one broad and one narrow continental mass, and one broad and one narrow oceanic area.*

The connection of Asia with Australia, through the intervening islands, is very similar to that of North America with

South America. The southern continent, in each case, lies almost wholly to the *east* of the meridians of the northern; and the islands between are nearly in corresponding positions,—Florida in the Occident corresponding to Malacca in the Orient, Cuba to Sumatra, Porto Rico to Java, and the more eastern Antilles to Celebes and other adjoining islands. It is, therefore, plain that Australia bears the same relation to Asia that South America does to North America. It is also true that Africa is essentially in a similar position with reference to Europe.

The northern portion of the Orient, or Europe and Asia combined, makes one continental area; and its general course is *east and west*. The northern portion of the Occident, or North America, is elongated from *north to south*.

4. Oceanic depression and Continental elevations.—The mean depth of the oceanic depression is about 12,000 feet; and the mean height of the land nearly one twelfth this amount, or 1,000 feet. The greatest depth reached by soundings (south of the Ladrões) is 27,450 feet; the greatest height on the land (in Mt. Everest of the Himalayas) is 29,000 feet; and hence the interval between the extremes of altitude and depression is over ten miles. If as much of the land were transferred to the oceanic depression as would bring both to a common level, the ocean would still have a depth of about 10,000 feet (Peschel).

The mean height of each, Europe, Asia, and South America, is, according to estimates, about 1,130 feet; of Africa probably not less than 1,130 feet; of North America, 750 feet; of Australia, 500 feet.

The mean depths of the great oceans (as calculated by Haughton from recent soundings) are: of the North Atlantic and North Pacific oceans, 15,000 to 15,500 feet; of the South Atlantic and South Pacific (and probably the Indian Ocean) about 13,000 feet.

5. The form of the ocean's bed.—The accompanying map shows the general form of the ocean's bed beneath the larger

oceans. From north to south, along the middle of the Atlantic, there is a wide zigzag ridge or plateau, *conforming in trend to the American coast*. It lies at a depth of 6,000 to 12,000 feet, while on either side the bottom slopes away to depths mostly between 15,000 and 20,000 feet. In the small area of 4,000 fathoms and over, situated to the northwest of the island of St. Thomas, the United States Coast Survey steamer "Blake" found, in 1883, a depth of 27,366 feet. This greatest depth and the largest Atlantic area of deep water exist in the *western* part of the ocean.

The Pacific also has a central relatively shallow plateau, having the direction of its longer axis between Fuegia and southeastern Asia; and its deepest portions are in its *western* half. One deep area is east of Japan; another, the deepest, south of the Ladrões.

Thus in each ocean the greatest depths are in the northern hemisphere and toward its western border. Northward in the northern hemisphere the ocean shallows rapidly. The depth in Behring's Straits is not over 150 feet; and between Great Britain and Iceland it does not exceed 6,000 feet, and is mostly under 600 feet.

The ocean's bottom has no steep ridges like those of ordinary mountain scenery. But broad elevations exist in some parts, as found in the soundings of the "Tuscarora" between the Hawaiian Islands and Japan. Besides these, there are many mountain ranges rising abruptly from the depths, having the islands of the ocean as their emerged summits, which rival in length those of the continents. The Hawaiian range, if the coral islands in the line of the volcanic islands are included (see following map), has a length of 2,000 miles; and it rises steeply from depths of 15,000 to 18,000 feet. The mountains of Hawaii have a height above the ocean of nearly 14,000 feet; and a depth of 17,000 feet was found but 50 miles south of the island; this making the whole height near 31,000 feet. The islands of the tropical Pacific make together an *island* chain about 5000 miles long;

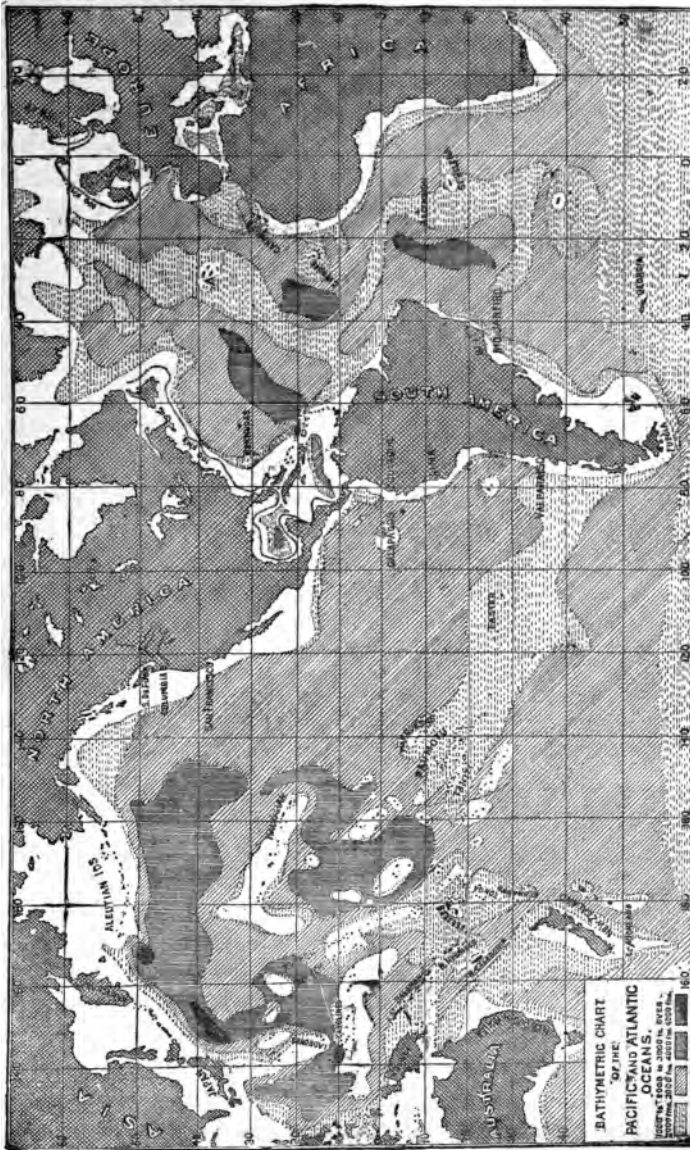


Fig. 2.

and they are the tops of a *mountain chain* of this great length.

6. True outline of the oceanic depression.—Along the oceanic borders the sea is often, for a long distance out, quite shallow, because the continental lands continue on under water with a nearly level surface; then comes, usually at

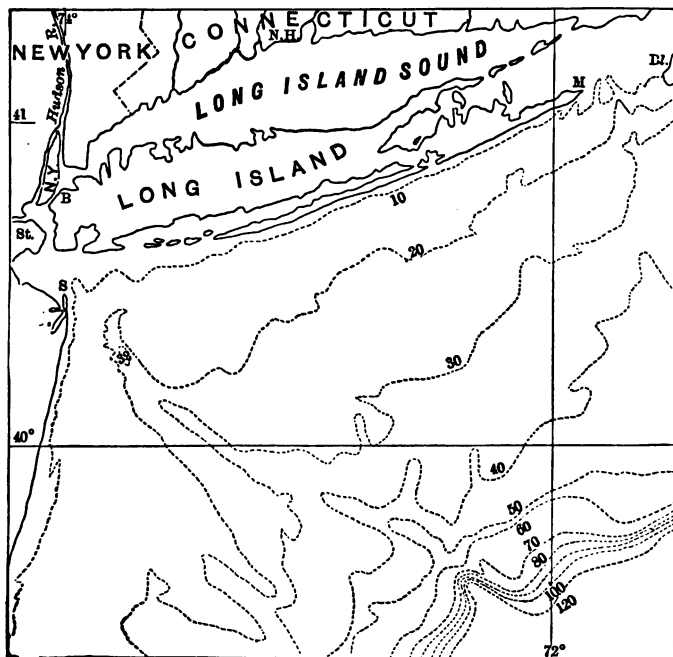


Fig. 3.

a depth of 100 fathoms or 600 feet, a rather sudden slope to the deep bed of the ocean. This is the case off the eastern coast of the United States, east and south of New England. Off New Jersey, as the annexed map represents, the deep water begins along a line about 80 miles from the shore; off Virginia this line is 50 to 60 miles at sea; and thus it gradually approaches the coast to the southward:

while to the northward it continues 80 to 100 miles off from the New England coast, and passes far outside of Nova Scotia and Newfoundland (see map, p. 11). The slope of the bottom, for the 80 miles off New Jersey, is only 1 foot in 700 feet. The true boundary between the continental plateau and the oceanic depression is the commencement of the abrupt slope. The same abruptness at the 100 fathom line exists in the Gulf of Mexico, as pointed out by J. E. Hilgard. The British Islands are situated on a submerged portion of the European continent, and are essentially a part of that continent, the limit of the oceanic basin — the 100 fathom line — being 50 to 100 miles outside of Scotland and Ireland, and extending south around the Bay of Biscay. West of the British Channel the depth increases, in a distance of only ten miles, from 100 fathoms to 2,000. New Guinea is in a similar way proved to be a part of Australia. Such facts occur on most coasts; and they teach that the oceanic depression is separated from the continental plateaus by a defined outline.

7. Surfaces of the continents. — The surface of a continent comprises (1) *low lands*, (2) *plateaus* or *table-lands*, and (3) *mountain-ridges*. The mountain-ridges may rise either from the low lands or the plateaus. The *plateaus* are great areas of the surface situated several hundred feet, or a thousand feet or more, above the sea, or above the general level of the low lands. They are often parts of the great mountain chains. Sometimes plateaus include a region between mountain-ridges, and sometimes the mass of the mountains themselves out of which the ridges rise. For example, the regions of Northern and Southern New York are plateaus (the former averaging 1,500 feet in height, the latter 2,000 feet) situated on the western borders of the Appalachian chain; and the same is true of the Cumberland Table-land in Tennessee. Between the Sierra Nevada and the Wahsatch there is a plateau of vast extent, having the Great Salt Lake in its northeastern portion; its height above the sea

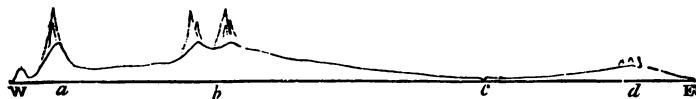
averages 4,000 feet; the high ranges of the Humboldt mountains rise out of it. The eastern part of New Mexico is a plateau of about the same elevation, called the Llano Estacado; and Mexico is situated in another, from which rise various ridges and peaks. The Desert of Gobi, between the Altai and the Kuen-Lun range, is a desert plateau about 4,000 feet high, while the plateau of Thibet, between the Kuen-Lun range and the Himalayas, is 11,500 to 13,000 feet above the sea. Persia and Armenia constitute another plateau. These examples are sufficient to explain the use of the term.

2. System in the Earth's Features.

1. General form of the continents resulting from their reliefs.

—The continents are constructed on a common model, as follows: *they have high borders and a low centre, and are, therefore, basin-shaped.* Thus, North America has the Appalachians on the eastern border, the Rocky chain on the west, and between these the low Mississippi basin. Fig. 4 illus-

Fig. 4.



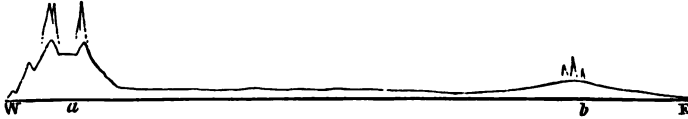
trates this form of the continent. In the section, *b* represents the Rocky Mountain chain on the west, with its lines of ridges at summit; *a*, the Washington chain (including the Sierra Nevada and Cascade range), near the Pacific coast; *c*, the Mississippi basin; *d*, the Appalachian chain on the east.

South America, in a similar manner, has the Andes on the west, the Brazilian Mountains on the east, and other heights along the north, with the low region of the Amazon and La Plata making up the larger part of the great interior. Fig. 5 is a transverse section from west to east (W, E), showing the

Andes at *a*, and the Brazilian Mountains at *b*. In these sections the height as compared with the breadth is necessarily much exaggerated.

In the Orient there are mountains on the Pacific side, others on the Atlantic; and, again, the Himalayas, on the

Fig. 5.



south, face the Indian Ocean, and the Altai face the Arctic or Northern Seas. Between the Himalayas (or rather the Kuen-Lun Mountains, which are just north) and the Altai, lies the plateau of Gobi, which is low compared with the enclosing mountains; and farther west there are the low lands of the Caspian and Aral, the Caspian lying even below the level of the ocean. The Urals divide the 6,000 miles of breadth into two parts, and so give Europe some title to its designation as a separate continent. West of their meridian there are again extensive low lands over Middle and Southern European Russia.

In Africa there are mountains on the eastern border, and on the western border south of the coast of Guinea; there are also the Atlas Mountains along the Mediterranean, and the Kong Mountains along the Guinea coast; and the interior is relatively low, although mostly 1,000 to 2,000 feet in elevation.

In Australia, also, there are high lands on the eastern and western borders, and the interior is low.

All the continents are, therefore, constructed on the *basin-like model*.

2. Relation between the heights of the borders and the extent of the adjoining ocean. — There is a second great truth with regard to the continental reliefs; namely, that *the highest border faces the largest ocean*.

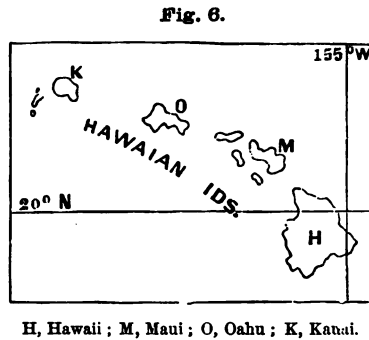
Each of the continents sustains the truth announced. North America has its great mountains, the Rocky chain, on the side of the great ocean, the Pacific; and its small mountains, the Appalachian, on the side of the small ocean. So, South America has its highest border on the west; and the Andes as much exceed in elevation and abruptness the Rocky chain as the South Pacific exceeds in capacity the North Pacific. The Orient has high ranges of mountains on the east, or the Pacific side, and lower, as those of Norway and other parts of Europe, on the west; and the Himalayas, the highest of the globe, face the great Indian Ocean (besides being most elevated eastward toward the great Pacific), while the smaller Altai face the small Northern Ocean. In Africa the eastern mountains, or those on the side of the Indian Ocean, are higher than those on that of the Atlantic. In Australia the highest border is on the Pacific side; for the South Pacific, taking into view its range in front of East Australia, is greater than the Indian Ocean fronting West Australia.

Hence the basin-like shape before illustrated is that of a basin with one border much higher than the other; and with the highest border on the side adjoining the largest ocean.

3. System in the earth's feature-lines. — The great masses of land and the larger peninsulas have in general a triangular outline, pointed southward. North and South America are prominent examples under the principle; Africa is another, and India and the peninsula of Greenland are others. This form is connected with the general fact that the directions of coast lines, mountain-ranges, and the ranges of islands in the ocean conform approximately to two systems of trends, one *northeastward* and the other *northwestward*.

North America derives its triangular outline (see map, p. 11) from the northeastward trend of the eastern coast and the northwestward of the western; and these trends are repeated in the mountain-ranges of the continent, the oldest and those of most recent origin. In South America the north

coast has the northwestern direction, and the east coast, the northeastern, and at the east cape the lines consequently make nearly a right angle. The northeastward trend characterizes the west coast of Europe and northern Africa, Scandinavia, and the mountains of Norway. Consequently the trough of the Atlantic and its zig-zag bottom "ridge" trend like the American coast. On the contrary, the trend of the Pacific ocean is parallel nearly with the west coast of North America, and is *northwestward*, like that of its central underwater plateau; and the course is at right angles to that of the north Atlantic. The islands of the Pacific are, as stated on page 10, grouped in long lines, or ranges, and nearly all these lines have a general parallelism to the longer axis of the ocean. One example, that of the Hawaiian or Sandwich Islands, is shown in Fig. 6. But New Zealand has the trans-



verse or northeastward trend, and this is continued in islands both to the north and south.

The two courses here pointed out vary toward north and south on one side, and east and west on the other, as shown in the ranges of islands northeast and north of Australia.

There are exceptions to the principle stated; but these would necessarily have come from the many diverse conditions on which the making of the earth's ranges of mountains and the outlining of its lands have depended.

The features described have a vast influence in adapting the continents for man.

America stands with its highest border in the far *west*, and with all its great plains and great rivers inclined toward the

Atlantic; for, through the Gulf of Mexico, the whole interior, as well as the eastern border, has its natural outlet *eastward*. Had the high mountains of the continent been placed on its *eastern* side, they would have condensed the moisture of the winds before they had traversed the land, and sent it back, in hurrying and almost useless torrents, to the ocean; but, being on the *western*, all the slopes, from the Atlantic to the tops of the Rocky Mountains, lie open to the moist winds, and fields and rivers show the good they thus receive.

Again, the Orient, instead of rising into Himalayas on the Atlantic border, has its great heights in the remote *east*, and its vast plains, even those of Central Asia, have their natural outlet *westward*, or toward the same Atlantic Ocean. Thus, as Professor Guyot has said, the vast regions of the world which are best fitted by climate and productions for man are combined into one great arena for the progress of civilization. Both the Orient and the Occident pour their streams and bear a large part of their commerce into a common ocean; and this ocean, the Atlantic, is but a narrow *ferriage* between them, and vastly better for the union of nations than connection by as much dry land: 3,000 miles of dry land would be, even in the present age, a serious obstacle to intercourse; while 3,000 miles of ocean draw the east and west only into closer political, commercial, and social relations.

PART II.

STRUCTURAL GEOLOGY.

THE term *rock*, in geology, is applied to all natural formations of rock-material, whether solid, like sandstones and slates, or loose sand and gravel. All sandstones were once beds of loose sand; and there is every shade of gradation, from the hardest sandstone to the softest sand-bed; so that it is impossible to draw a line between the consolidated and unconsolidated. Geology does not attempt to draw the line, regarding *consolidation* as an accident in the history of the earth's beds or deposits: an accident that probably happened to not a thousandth part of the sand-beds and mud-beds that have existed; and yet, to enough of them in each period for the preservation of the wonderfully varied records that are the materials of geological science.

Rocks may be studied simply as rocks,—that is, with reference to their composition,—and collections may be made containing specimens of their various kinds. Again, they may be studied as rock-masses spread out over the earth and forming the earth's crust; and, with this in view, the condition, structure, and arrangement of the great rock-masses, sometimes called *terranes*, would come up for consideration. The two subjects under Structural Geology are, therefore: 1. **Petrology, or the Constitution of Rocks;** 2. **The Condition, Structure, and Arrangement of Rock-masses or Terranes.**

I. — PETROLOGY.

1. General Observations.

Rocks consist essentially of minerals, and the minerals of the common rocks are of four groups : —

1. QUARTZ, called in chemistry, *silica* and *silicon dioxide*.
2. SILICATES, or compounds of silicon in the dioxide state with other substances.
3. CARBON, the chief element of charcoal and mineral coal, and a constituent of carbonic acid or carbon dioxide.
4. CARBONATES, or compounds of carbon in the dioxide state with other substances.

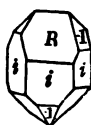
1. QUARTZ, OR SILICA. — Quartz far exceeds all other species in abundance. It consists of one atom of silicon and two of oxygen, its formula being SiO_2 . It is one of the hardest of common minerals; does not melt before the blow-pipe, and does not dissolve in water, or in the ordinary acids. Its hardness and durability especially fit it for this place of first importance in the material of the earth's foundations.

It is often seen in crystals like Figs. 7, 8, though generally occurring in massive forms, or in grains or pebbles. It is

Fig. 7.



Fig. 8.



distinguished ordinarily by its glassy aspect, whitish or grayish color, and an absence of all tendency to break with a bright even surface of fracture (a quality of crystals called *cleavage*). Although usually nearly colorless or white, it is often reddish, yellowish, brownish (especially smoky brown),

and even black; and the lustre is sometimes very dull, as in *chalcedony*, *flint*, and *jasper*. The sands and pebbles of the sea-shores and gravel-beds are mostly quartz, — because quartz resists the wearing action of waters better than any

other common mineral. For the same reason, most sandstones and conglomerates consist mainly of quartz.

The hardness (on account of which it scratches glass easily), infusibility, insolubility, non-action of acids, and *absence of cleavage* are the characters that serve to distinguish quartz from the other ingredients of rocks.

But while quartz is so refractory, it easily fuses when mixed and heated with potash, soda, lime, or an oxide of iron, into *glass*. Ordinary glass is made by mixing powdered quartz with soda or potash and sometimes lime, and subjecting the mixture to a high heat. Sodium carbonate is hence conveniently used in blow-pipe experiments for distinguishing quartz.

Although quartz is one of the original minerals of the earth's crust, and has been mostly derived from the earlier rocks of the globe, part of it has passed through living beings, either plants or animals and is of *organic* origin; for some of the lowest species of these kingdoms of life have the power of making, by secretion, siliceous shells or siliceous particles or spicules in their texture; and beds of limited extent have been made of these microscopic siliceous shells and spicules. (See page 67).

2. SILICATES.—Many of the common rock-making minerals are silicates, or combinations of silicon with certain basic elements and oxygen; that is with the constituents of the bases *alumina*, *magnesia*, *lime*, *potash*, *soda*, *oxides of iron*, and a few others.

Pure *alumina* is the most important of the above-mentioned bases. It consists of aluminum and oxygen (Al_2O_3). It is very hard, infusible, and insoluble, and therefore adapted to its place as *second* in abundance to silica. When crystallized, it is the hardest of all known substances, excepting the diamond, it being the gem *sapphire*, and the essential ingredient of *emery*. The species is called *corundum* in mineralogy.

Magnesia (magnesium and oxygen, Mg O), well known

under the form of *calcined magnesia*, is as hard as quartz when crystallized, and equally infusible and insoluble.

Lime (calcium and oxygen, Ca O) is common quick-lime, the *calx* of the Romans, whence the term *calcium* for the metal.

Potash (potassium and oxygen, $\text{K}_2 \text{O}$) and *soda* (sodium and oxygen, $\text{Na}_2 \text{O}$) are the alkalies ordinarily so called.

Iron protoxide (Fe O) and *Iron sesquioxide* ($\text{Fe}_2 \text{O}_3$) are the two oxides of iron whose constituents exist, like those of the above bases, in many silicates.

The silicates which contain only the constituents of alumina are infusible, as well as very hard. But those which contain the elements of either of the other bases mentioned are with few exceptions fusible, and therefore fit to be the ingredients of igneous or volcanic rocks.

The following are the most common of these silicates:—

1. **Feldspar.**—The feldspars are *silicates*, containing the constituents of alumina, a sesquioxide, along with those of the protoxide bases, potash, soda, or lime. They are hard enough to scratch glass, but less hard than quartz. They break easily, or have *cleavage, in two directions*, with flat lustrous surfaces; and the two cleavage-surfaces meet *nearly or quite at a right angle*. The color is usually white or flesh-red, and rarely dark brown or greenish. The specific gravity is 2.4—2.7.

The most common kind is a *potash* feldspar, and is called *orthoclase*; another, named *albite*, is a *soda*-feldspar; two others, *oligoclase* and *labradorite* are *soda-lime* feldspars.

2. **Mica.**—Mica is a *silicate* containing the constituents of *alumina*, along with those of *potash* and *lime*, like the feldspars, but also those of *magnesia* and *oxide of iron*. Mica cleaves easily into tough leaves, thinner than the thinnest paper, which are somewhat elastic. It fuses with great difficulty. Its most common colors are whitish, brownish, and black. On account of its easy cleavage, transparency, and difficult fusibility, it is often used in the doors of stoves. The most common kind of mica has a light color and is

called *muscovite*; another, usually black in color (because of the amount of iron present), is called *biotite*. Some micas contain water, that is, are hydrous; and these *hydro-micas*, as they are called, are pearly in lustre, feel a little soapy, and are sometimes mistaken for talc.

The minerals, quartz, feldspar, and mica are the constituents of granite; and they may be distinguished in it as follows: the grains of *quartz*, by their more glassy lustre, grayer color, and want of cleavage; the grains of *feldspar*, by their cleavage; the grains of *mica*, by their very easy cleavage by means of the point of a knife-blade into thin elastic leaves.

3. Chlorite.—Resembles black mica in constitution, and, when well crystallized, in its cleavage; but it contains 14 per cent of water and no potash. Moreover its leaves are not elastic, its color is usually dark green, and it feels a little greasy. It is often fine granular.

4. Hornblende and Pyroxene.—Hornblende and pyroxene are silicates of magnesium, calcium and iron, aluminum not being an essential constituent. The usual kind of each in rocks is black, or greenish black, and 2.8 to 3.2 in specific gravity; but white and light green varieties are common. They equal feldspar in hardness; unlike mica, they are brittle. The crystals or crystalline grains have two equal shining cleavages; in hornblende the angle between the two is about 124° , in pyroxene, 87° . Hornblende is often in long slender crystallizations, and *asbestos* is a variety of it. Both make hard and tough rocks. Pyroxene is a constituent of trap, and of a large part of igneous rocks.

5. Talc; Serpentine.—Talc and serpentine are *hydrous silicates of magnesium*. They both have a greasy feel,—especially talc. *Talc* is very soft, so soft that it does not feel gritty to the teeth. It is often in foliated plates or masses like mica; but the folia, or leaves, though separating rather easily, and flexible, are not elastic. The usual color is pale green. *Soapstone* or *steatite* is a massive variety of talc, of whitish, grayish, or greenish color.

Serpentine.—Contains much water (14 per cent). It is usually a dark-green massive mineral or rock, of a very fine-grained texture, and soft enough to be cut with a knife.

6. The following minerals occur distributed in crystals through many crystalline rocks:—

Garnet; Tourmaline.—These species, like the micas, are aluminum silicates of magnesium, calcium and iron. *Garnet* is often in dark red, brownish, or black crystals of 12 or 24

Fig. 9.

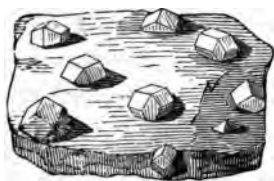


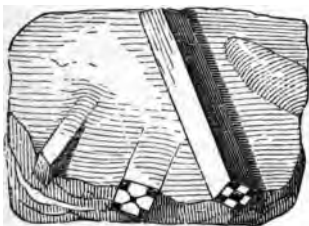
Fig. 10.



sides (dodecahedrons or trapezohedrons). The first of these forms is represented in Fig. 9, showing garnets distributed through a mica schist. *Tourmaline* (Fig. 10) is generally in

oblong 3, 6, 9, or 12-sided crystals, shining and black; also at times blue-black, brown, green, and red.

Fig. 11.



Andalusite is simply an *aluminum silicate* and hence is infusible. It is found in imbedded crystals in clay slate, and sometimes in mica schist; the form is nearly a square prism. The interior of the crystals is very frequently black or grayish-black at the centre and angles (Fig. 11), while the rest is nearly white; and this variety is called *macle*, or *chiastolite*.

terior of the crystals is very frequently black or grayish-black at the centre and angles (Fig. 11), while the rest is nearly white; and this variety is called *macle*, or *chiastolite*.

Cyanite.—Has the same composition as the preceding,

and like it is infusible. Usually occurs in mica schist or gneiss in thin, blade-like, pale blue crystals.

Staurolite. — Related to the last two minerals, and infusible, but it contains some iron. Its crystals are stout prisms of 128° of black or brown color; they often have the form of a cross, whence the name, from *σταυρός* a *cross*.

3. **CARBON.** — Carbon occurs pure among minerals only in *diamond* and *graphite*. It is the chief element in *mineral coal*, but is combined in it with more or less of hydrogen and oxygen, and also some nitrogen. *Charcoal*, the *carbo* of the Romans, is nearly all carbon.

1. **Diamond; Graphite.** — *Diamond* and *graphite* are both pure carbon, but in different molecular states; the former, the hardest of minerals, crystallizing in octahedral and related forms; the latter, one of the softest, crystallizing in hexagonal plates, with nearly the easy cleavage of mica and the lustre of steel. Graphite is also called *plumbago* and *black-lead*, and is the material of the mis-named *lead-pencils*. It occurs in crystalline rocks in scales and masses, and is ground up and subjected to pressure to prepare it for making pencils.

2. **Mineral Coal; Mineral Oil.** — Mineral coal is not a true mineral. It constitutes beds in various rock-formations, and has been formed from wood or some kind of vegetable material. There are three prominent kinds, differing in the amount of oxygen and hydrogen that is present with the chief ingredient carbon, and consequently in the amount of inflammable gas given out on burning. This gas generally consists simply of carbon and hydrogen, and is largely the carbo-hydrogen used in illumination.

1. *Anthracite* contains over 85 per cent of carbon. It yields little that is volatile, and burns with a feeble blue flame.

2. *Bituminous Coal* has less hardness and lustre than anthracite, contains usually 70 to 80 per cent of carbon, and gives out on heating 20 to 40 per cent of volatile matter. It

hence burns with a bright yellow flame. It is the source of illuminating gas, and will yield also mineral oil. *Cannel coal* is a compact bituminous coal having a feeble lustre; it often yields 40 to 50 per cent of volatile matter, and is an available source of mineral oil. *Bituminous coal* is called *caking* coal when it softens in the fire and cakes at surface, so that a fire made of it requires poking to make it burn freely; *non-caking* kinds have not this quality, and hence are preferable for fuel and economical purposes.

3. *Brown Coal* differs from bituminous coal in its brownish-black powder, and in containing 2 or 3 times as much oxygen (15 to 25 or more per cent). The mineral coal from rocks more recent than the true Carboniferous formation is often improperly called *brown coal*, even when good bituminous coal, without a brownish color to the powder. The name *lignite* is sometimes also applied to it; but true lignite is coal that retains the fibrous texture of the original wood.

4. *Mineral Oil* is liquid carbo-hydrogen, and is chemically related to illuminating gas. It was formed out of animal or vegetable materials. Illuminating gas is often produced in great quantities from the wells or sources yielding mineral oil, and in some villages in oil regions the houses are heated and lighted by it. Many black shales yield mineral oil when heated. They do not contain the oil, but instead a peculiar carbo-hydrogen compound (not yet satisfactorily investigated) which yields the oil on heating. Mineral oil on long exposure to the air combines with oxygen and finally becomes a black fusible bitumen, or a coal-like substance having little or no fusibility.

3. **Carbonic Acid**, or *Carbon dioxide* (CO_2), is a gas containing 27.65 per cent of carbon and the rest oxygen. It constitutes 3 out of 10,000 parts by volume of the atmosphere, and is carried from the atmosphere to the earth by the rains. It is formed in the combustion of wood, combustion consisting chiefly in the combining of oxygen with the constituents of the wood. It is also given out in the respiration of

animals, the processes of life in animals being carried forward through a sort of combustion, or a similar combination of oxygen with the materials of the tissues.

4. CARBONATES. — Compounds containing the elements of *carbonic acid* or *carbon dioxide* with those of lime, magnesia, etc.

1. **Calcite**, or *Calcium carbonate* (Ca C O_3). — The material of limestone and marble. It crystallizes in many forms, a few of which are represented in Figs. 12, 13. Its colors are very various. It cleaves easily in three directions with bright surfaces, as may be seen on examining even the grains of a fine white marble. It is so soft as to be easily scratched with a knife; dissolves in diluted acid (hydro-chloric) with effervescence, that is, with an escape of carbonic acid gas; and when heated (as in a lime-kiln or before the blow-pipe) it burns to *quick-lime* without melting. By its effervescence with acids it differs from all the minerals before mentioned.

Fig. 12.

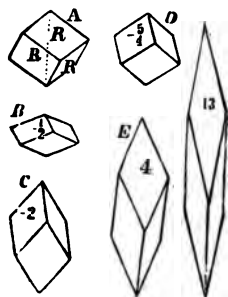
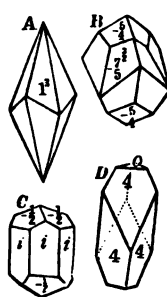


Fig. 13.



2. **Dolomite**, calcium-magnesium carbonate ($\frac{1}{2}\text{Ca } \frac{1}{2}\text{Mg C O}_3$); that is, it differs from calcite in containing magnesium in place of half of the calcium. Very much of the so-called limestone of the world is *magnesian* limestone. It closely resembles common limestone, but may often be distinguished by its effervescing scarcely at all with acid unless heat be applied. The trial may be made by dropping a particle, as

large as half a grain of wheat, into a test-glass containing a mixture, half and half, of hydro-chloric acid and water.

For *iron-carbonate* (siderite) see next page.

5. **CHLORIDES.** — The only chloride forming rock-masses is **Common or Rock Salt.** — It is *sodium chloride* (Na Cl). It is easily distinguished by its taste. It constitutes beds, more or less impure, in strata of various ages from the Silurian to recent time; which is accounted for by the fact that the universal ocean is its source, and simple evaporation the means of depositing it. Silurian rock salt occurs in Western New York and Canada; and a great recent (early Quaternary) deposit, nearly 40 feet thick and remarkably pure, occurs at Petit Anse, La., near the Gulf of Mexico. The saline constituents of the ocean's waters constitute about 3.53 parts in 100; of which three-fourths or 2.65 are common salt, the rest being, — magnesium chloride 0.32, magnesium sulphate 0.19, potassium chloride 0.12, calcium sulphate, or gypsum, 0.16, sodium bromide 0.06 = 3.53, with traces also of other ingredients.

6. **IRON ORES.** — Iron ores are widely distributed in rocks, and some of them form thick beds. Unlike the minerals mentioned above they have a specific gravity above 3.5. The most important are three *oxides*, two *sulphides*, and a *carbonate*.

1. **Hematite**, or *iron sesquioxide* ($\text{Fe}_2 \text{O}_3$). It yields a *red powder*, whence its name given it by the old Greeks, from *aiua blood*. Its crystals have usually an iron-black color, and high lustre; but it is deep red when earthy or impure. It is the source of the color in red sandstones and other red rocks.

2. **Limonite**, or *hydrous iron-sesquioxide*, equivalent to 2 of $\text{Fe}_2 \text{O}_3$ to 3 parts of water. It has a brownish-yellow powder. It varies in color from black to brown and yellow. While *red ochre* of painters is impure hematite, *yellow ochre* is impure limonite. Limonite is the coloring ingredient in a large part of the brown and brownish yellow rocks and clays. The

water present goes off on heating and hence the mineral, and all rocks colored by it, when heated *turn red*. It is formed from the oxidation of various iron-bearing minerals (page 82), and often makes deposits in marshes, whence its name from the Greek for *marsh*.

3. Magnetite.—Magnetite has an iron-black color, like hematite; but it is attracted by a magnet, and has, besides, a *black powder*. It consists of 3 of iron to 4 of oxygen (Fe_3O_4). It is common in grains in a large part of rocks, the calcareous (or limestones) excluded, and among the sands of seashores and soils; and like hematite, constitutes great beds in some of the older rocks.

Iron protoxide never occurs as a mineral.

4. Pyrite.—An *iron-sulphide*, (FeS_2) of a brass-yellow color and as hard nearly as quartz. It will strike fire with a steel, and was named by the Greeks from $\pi\upsilon\rho$, fire. It is common in rocks, in massive forms, crystals (often cubes), and in grains. *Pyrrhotite* is the name of another common iron-sulphide containing proportionally less sulphur (Fe_7S_8), having the grayish yellow color of bronze, and so soft as to be easily scratched with the point of a knife.

5. Siderite, or *iron carbonate* (FeCO_3), called also *spathic iron*. It has approximately the cleavage and form of calcite when crystallized, but is usually grayish in color. It changes readily on exposure to brown (and to limonite), and is much heavier than calcite, its specific gravity being 3.7 to 3.9. It effervesces in heated dilute hydro-chloric acid, like dolomite.

The “iron-stone” or “clay iron-stone” of coal regions and others, used as an ore of iron, is very often siderite; but it is often also hematite, and sometimes limonite.

2. Kinds of Rocks.

1. Fragmental and Crystalline Rocks.—The minerals of which a rock consists may be either (1) in *broken* or *worn* grains or pebbles, like those of sand or mud or a bed of gravel; or, on the contrary, (2) they may be in *crystalline* grains, in

which case they were formed where they now are at the time of the crystallization of the rock. Such crystalline grains are angular, as may be seen on a surface of fracture, and, in the case of most minerals excepting quartz, show surfaces of cleavage. Common white marble and granite are good examples of rocks having a crystalline texture; and also loaf-sugar and steel, among products of art.

The rocks of the first kind, consisting of fragments of other rocks, are called *fragmental* rocks; and those of the latter kind, *crystalline* rocks.

2. Fragmental rocks. — These are the most common of rocks. They constitute the chief part of the twenty miles of beds, in depth (page 1), open to geological study. The wear and decomposition of the oldest rocks produced the fragmental material for those of the next age, and so on through geological time; and the rocks made of such material, as, for example, sandstones, shales, and conglomerates, are the *fragmental* rocks. They are *stratified* rocks also, because they are in beds. They are also called *sedimentary* rocks, because the material was in most cases deposited as a sediment from waters. Most limestones also are fragmental rocks, as explained on page 31.

Intermediate between rocks that are obviously *fragmental* and *crystalline* there are others, of a flinty compactness, which show no distinct grains, and are therefore not easily referred to either division. To determine the division to which such rocks belong, the beds affording them and others associated have to be studied. If these associated rocks are *fragmental*, then the compact beds are probably so also; but if these are *crystalline*, then they are probably related to the crystalline. Experience among rocks is required to decide correctly in all such cases. The examination of thin transparent slices with the microscope is sometimes the only means of distinguishing the two kinds.

The crystalline rocks are either *metamorphic* or *igneous*.

3. Metamorphic rocks are those which have been changed

(*metamorphosed*) into *crystalline* rocks, and usually without fusion. The rocks so changed are the ordinary fragmental rocks and limestones. The alteration, when most perfect, has consisted in a complete crystallization of the rock, and, when least so, in its consolidation; between which extremes all gradations exist. Examples of metamorphic rocks are architectural marble, mica schist, gneiss, and much granite.

4. Igneous rocks are those which have come up melted through volcanic vents, or through fissures opened to some seat of melted rock within or below the earth's crust. They include lavas, part of porphyry and granite, and other rocks described beyond (page 37).

It appears from the definitions above given that the *fragmental* rocks have come from the working over and redistribution of *surface* rock-material; and the *metamorphic*, from the crystallizing in certain regions, through some means, of fragmental rocks. Of the three kinds, *igneous* rocks alone have added to the amount of surface material. Besides these, many veins contain mineral material from the earth's depths.

5. Calcareous rocks. — Calcareous rocks, so named from the Latin *calx* lime, are the *limestones*. To a great extent they are of *organic* origin, that is, have been formed from pulverized animal relics, such as *shells* and *corals*; and in this case they are properly *fragmental* or *sedimentary* beds, although so finely compact that this might not be suspected from their texture.

Some limestones have been made from the accumulation and consolidation of minute shells, called *Rhizopods*. These shells being generally no larger than grains of sand, powdering was not necessary. The limestone rocks formed of them hence may not be *fragmental*. Still, even these minute shells are generally broken. *Chalk* is an example.

Limestones of *mineral* origin, that is, those made from earlier limestones, occur, but are not very common. Limestone conglomerates are of this kind.

Other calcareous rocks have been *deposited from waters holding the material in solution*, and are, therefore, of *chemical origin*. Of this kind is the *travertine* of Tivoli near Rome in Italy, and of Gardiner's River in the geyser region of the Yellowstone Park, and similar beds in many regions of mineral springs, besides the petrified moss and trees of some marshy places.

6. Siliceous rocks. — Siliceous rocks are those that consist largely of quartz, or silica. The name is from the Latin *silice*, signifying *flint*, a variety of quartz. Siliceous material, or quartz, like the calcareous, is, as stated on page 21, of both *mineral* and *organic* origin; but the mineral is vastly the most abundant. It is also to a small extent a *chemical product*, as in the siliceous depositions about geysers (page 142). The silica of organic and chemical origin is usually in the state of opal-silica. Opal-silica has less hardness and specific gravity than quartz; but by solution and consolidation, generally becomes true quartz, as in flint.

7. Hydrous rocks. — A *hydrous* mineral is one containing water; and a *hydrous rock* contains a hydrous mineral among its constituents (page 23).

8. Porphyritic rocks. — A porphyritic rock is one having distinct crystals of feldspar disseminated through it, so that, when polished, the surface appears spotted with a light-colored mineral, usually between an eighth of an inch and two inches in length. The red porphyry of Egypt and the green porphyry of the eastern borders of Greece, much used for ornamental purposes by the ancients, are typical examples. Granite, gneiss, syenite, diorite, and other rocks are said to be *porphyritic* when similarly spotted.

9. Massive, schistose, laminated, slaty, shaly rocks. — Rocks are termed *massive* when there is no tendency to break into slabs or plates, as in the case of granite and most conglomerates; *schistose*, if crystalline, when breaking into slabs or plates, owing to the arrangement in layers of the mineral ingredients, especially the mica or the hornblende; *lami-*

nated, when splitting into slabs or flagging-stones, but not in consequence of a crystalline structure; *slaty*, when dividing easily into thin, even, hard slates, like roofing slate; *shaly*, when dividing easily into thin plates like slate, but the plates irregular and often fragile.

The term *schist* is applied to a schistose rock; *flag*, to a laminated rock; *slate*, to a slaty rock; *shale*, to a shaly rock.

The *kinds of rocks* are here described under the four heads:

1. **Fragmental Rocks**, not calcareous; 2. **Metamorphic Rocks**, not calcareous; 3. **Calcareous Rocks**; 4. **Igneous Rocks**.

1. **Fragmental Rocks, not Calcareous.**

The fragmental material which the wear and decomposition of rocks ordinarily produces is either: (1) *sand*; (2) *gravel*; (3) *mud*, or *earth*: or (4) *clay*; or mixtures of these materials. Hence these are the constituents of the fragmental rocks, and they determine their kinds.

1. **Sand-beds; Gravel-beds.** — Most sand or gravel consists chiefly of quartz; but some beds are made of granite sand or pebbles, or of fragments of other rocks. Some contain much clay, or are *argillaceous* (so named from *argilla*, clay); some are red or brownish yellow, owing to the presence of iron-oxide, and are hence *ferruginous*. Some will effervesce slightly with acid, and are hence *calcareous* (page 31). Beach sands often contain red grains of garnet; and commonly black grains of magnetite, which a magnet easily attracts.

2. **Mud; Earth; Clay.** — Mud and earth contain, besides grains of quartz, some pulverized feldspar, or else clay, with more or less of other minerals. The terms *argillaceous*, *ferruginous*, *calcareous*, are here applied as above; the calcareous grains are usually derived from the grinding up of shells. When *black* the color is due to carbonaceous material derived from vegetable or animal decomposition.

Common clay is a mixture of pure clay with grains of quartz, feldspar, and usually traces of hydrous iron-oxide,

(limonite), or else iron-carbonate. Owing to the iron, it burns *red*, making red brick—heat changing the iron-mineral present to hematite (page 28). Occasionally, as in certain Milwaukee clays, the iron is in an iron-silicate, so that the heat cannot oxidize it; and consequently the brick it makes are not red. Clays free from iron are required for white pottery; and free also from grains of feldspar for making *fire-brick*, because the *potash* of feldspar makes clay fusible.

Pure clay, or *kaolin*, is white, and feels greasy. It is an aluminum silicate containing 14 per cent of water. It results from the decomposition of feldspar (page 84). It is used in making fine pottery and porcelain, and paper.

3. **Sandstone.**—A rock made of sand, of red, gray, brown, white and other colors. When of quartz sand it is a *quartzose* or *siliceous* sandstone; if of granite sand, a *granitic*; if fine earthy or clayey, an *argillaceous* sandstone. It makes a durable building stone when firm, if not much absorbent of water when immersed in it, and *if free from pyrite* so as not to rust on exposure. The brownish red is often called freestone. The sandstone used for grindstones is even-grained and more or less *friable*.

4. **Conglomerate.**—Consolidated gravel. If the stones are *rounded* the rock is often called a *pudding-stone*; and if *angular* fragments, a *breccia*; if the pebbles are of quartz, a *siliceous conglomerate*; if of limestone, a *calcareous conglomerate*. The stones may be a foot or more in diameter, though usually much smaller.

5. **Shale.**—A somewhat slaty rock made of clay or clayey earth or fine mud. The colors are of all dull shades from gray to red and black. *Carbonaceous* shale is the blackish kind, yielding mineral oil when heated.

6. **Tufa.**—A volcanic sandstone, composed of volcanic sand or pulverized volcanic rocks: the color is usually brownish, brownish-yellow, grayish, or reddish.

2. Metamorphic Rocks.

1. **Granite.** — A crystalline rock, consisting of quartz, feldspar, and mica. Color, usually light or dark gray, or flesh-red, the latter shade derived from a flesh-colored feldspar: the quartz, uncleavable and usually grayish-white in color; the feldspar, white to flesh-red, and yielding smooth, shining surfaces by cleavage; the mica, white to black, and affording thin, flexible leaves by cleavage.

2. **Gneiss.** — Like granite in constitution, but having a bedded structure, owing to the arrangement of the minerals, the mica especially being in parallel planes; it has, therefore, a banded appearance on a surface of transverse fracture. If the color of the gneiss is dark gray, it is banded usually with black lines consisting largely of black mica. Along the micaceous planes it breaks rather easily into slabs, which are sometimes used for flagging.

3. **Mica Schist.** — Related to gneiss, but consisting more largely of mica, with usually more quartz and less feldspar, and, in consequence of the mica, breaking into thin slabs. The slabs have a glistening surface. In regions of mica schist the dust of the roads is often full of shining particles of mica.

4. **Syenite; Hornblendic Gneiss; Hornblendic Schist.** — *Syenite* resembles granite, but contains *hornblende*, a black, brittle mineral, in place of mica. A rock like gneiss, but containing hornblende in place of mica, is called *syenite gneiss*. A black or greenish-black rock consisting almost wholly of hornblende and schistose is called *hornblende schist*; or if not schistose, *hornblendyte*.

5. **Hydromica Schist.** — A slaty, fine-grained mica schist feeling somewhat greasy to the fingers. It used to be called *talcose slate*; but it contains a hydrous mica instead of talc.

6. **Chlorite Schist.** — A slaty rock containing the olive-green mineral chlorite (page 23), (which gives it a dark green color.) Much hydromica schist is *chloritic*.

7. **Slate, Argillyte, Phyllyte.** — Names of roofing-slate and allied slaty rocks. The texture is hardly crystalline to the naked eye. The slates in the most perfect kinds are hard, smooth in surface, and not absorbent of water. Color, blue-black, purplish, red, greenish, and of other shades. Much slate is a hydromica schist of very fine grain.

There is a gradual passage of the above rocks from granite into gneiss; from gneiss into mica schist; and from mica schist, hydromica schist, and chlorite schist into argillite.

8. **Quartz Rock; Quartzyte.** — Names applied to the sandstone of a metamorphic region. Quartzyte is usually very hard. It differs from massive quartz in consisting (as seen under a lens) of *grains* of quartz. *Itacolumite* or *flexible sandstone*, is a laminated porous quartzite containing minute scales of a hydrous mica, and having some flexibility. Occurs in the gold regions of North Carolina and Brazil.

9. **Dioryte.** — Near syenite; but the feldspar is not orthoclase, as in syenite, but oligoclase or labradorite. It is a coarse or fine grained rock, grayish white to dark green in color, and sometimes almost black.

3. Calcareous Rocks.

a. Non-metamorphic.

1. **Common Limestone.** — A compact rock of grayish and other dull shades of color to black, consisting either of calcite or dolomite, but often impure from the presence of clayey or earthy material. It breaks with little or no lustre. If containing fossils it is called *fossiliferous* limestone; if the fossils are corals, *coral* limestone; if remains of *crinoids*, *crinoidal* limestone. For the distinctive characters, see page 27. When impure, and therefore good for making hydraulic lime (quick-lime that will make a cement which sets under water), it is called *hydraulic* limestone. *Chalk* is a variety of limestone soft enough to be used for marking.

Many varieties of common limestone are polished and used as *marbles*; they have black, reddish, yellow, gray, and other colors; kinds containing fossil shells are called *shell-marbles*.

2. **Oölyte.** — A limestone consisting of concretions as small as the roe of fish, or smaller, — whence the name, from the Greek *ὄον*, *egg*. Oölite or oölitic limestone occurs in all the geological formations, and is forming in modern seas about the Florida keys and other coral reef regions.

3. **Travertine.** — *Stalactites* are limestone concretions hanging from the roofs of caverns; and *stalagmite* is the same material covering the floors; both are formed from the calcareous waters that come through the roof, and are sometimes called *dripstone*. A similar deposit from streams or ponds is called *travertine*; it is sometimes used for a building stone. *Petrified leaves* and *moss* are made by the same kind of waters.

b. Metamorphic.

Crystalline Limestone; Architectural and Statuary Marble. — Limestone having a crystalline texture, and, consequently, glistening on a surface of fracture. A pure white kind, of fine grain, is used for statuary, and both this and coarser varieties for marble buildings. Most of the clouded marbles are here included.

4. Igneous Rocks.

The following igneous rocks are of two series: I., the *Hornblende-pyroxene* series, containing, besides the feldspar, much hornblende or pyroxene; specific gravity above 2.75; colors usually dark, from black to red and dark gray. II. The *Feldspathic* series, the feldspar greatly predominating, with little or no hornblende or pyroxene; specific gravity under 2.75; colors usually light gray to red.

1. **HORNBLLENDE-PYROXENE SERIES.** — 1. **Syenite** and **Dioryte** (pp. 35, 36) occur as igneous rocks as well as metamorphic. The latter is often a very fine-grained compact rock, and when

it contains disseminated feldspar crystals makes a variety of *porphyry*. The *red porphyry* of Egypt contains in the mass oligoclase and hornblende, and has disseminated crystals of orthoclase. The *green porphyry* (or oriental verd-antique) has labradorite and pyroxene in its compact mass, and hence is more closely related to the following kind, dolerite. These porphyritic rocks are supposed to be igneous.

2. **Dolerite** consists of the *feldspar* labradorite and *pyroxene*, and has greenish-black, brownish-black, and black colors. It is also often called *trap*. It may be either crystalline-granular, or of a flinty compactness. It contains also grains of magnetite. *Basalt* is a compact variety. *Diabase* is another name for dolerite, used especially for dolerite older than Tertiary. Chloritic dolerite is sometimes called *melaphyre*.

3. **Peridotite** is a dolerite containing grains of a green silicate, of a bottle-glass green color, called *chrysolite* or *olivine*.

4. **Amphigenyte**. — The common lava of Vesuvius, containing a white potash-bearing mineral, called *leucite* (which is garnet-like in its form) instead of a feldspar, and with it pyroxene.

2. FELDSPATHIC SERIES. — 1. **Granite** is here included so far as it is an igneous rock.

2. **Trachyte**. — Consists generally of orthoclase feldspar, partly a glassy kind (sanidin), and has a rough surface. Hornblende is often sparingly present, and sometimes quartz.

3. **Felsyte**. — Consists chiefly of orthoclase feldspar, like ordinary trachyte, but is without glassy feldspar crystals and has a smooth surface of fracture. Some quartz is often present. *Felsyte-porphry* consists of orthoclase in a compact condition, with disseminated crystals of the same feldspar of a paler color; so that a polished surface is covered with angular spots. The color is often red and the rock then resembles the red porphyry mentioned under dioryte; but its specific gravity is under 2.75.

4. **Lava**. — Any rock that has flowed in streams from a volcano, especially if it contains cavities, or, in other words, is

more or less scoriaceous. The most common kinds are *dolerite*, *peridotite*, or *trachyte* in composition.

Scoria is a light lava, full of cavities; and *pumice*, a white or grayish feldspathic scoria, having the air-cells long and slender, so that it looks as if it were fibrous.

Obsidian is volcanic glass, and *Pitchstone* and *Pearlstone* are rocks that have a texture between that of stone and glass.

In the cooling of melted rock, the mass, if the process goes on rapidly, may become glass throughout with only occasional crystalline grains or stony points (called *microlites* from their minuteness) scattered through it. With slower cooling the stony points are more abundant, and may predominate, or they may make up the whole of the mass, excepting perhaps some points which still remain as glass. These peculiarities are detected only by the microscopic investigation of thin slices. Frequently the microscope detects an arrangement of the grains in lines indicating the flow of the material when liquid, or what has been called a *fluidal* structure.

II.—CONDITION, STRUCTURE, AND ARRANGEMENT OF ROCK-MASSSES.

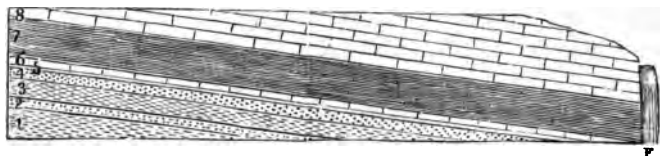
The rocks above described are the material of which the great rock-masses or terranes of the globe consist. These rock-masses occur under three conditions:—1. *The Stratified*; 2. *The Unstratified*; 3. *The Vein-form*.

1. The Stratified condition.—Stratified rocks are those which lie in beds or strata. The word *stratum* (the singular of *strata*) is from the Latin, and signifies that which is *spread out*. The earth's rocky strata are spread out in beds of vast extent, many of them being thousands of square miles in area and thousands of feet in thickness.

The stratified rocks exposed to view over the earth far exceed in surface the unstratified. They are the rocks of

nearly the whole of the United States and of almost all of North America, and not less of the other continents. Throughout Central and Western New York, and the States south and west, the rocks, wherever exposed, are seen to be made up of a series of beds. And if the rocks are less distinctly stratified over most of New England, it is, in general, only because the structure has been partly obscured by the upturning and crystallization which they have undergone since they were formed.

Fig. 14.



The preceding figure represents a section of the rocks along the river below Niagara Falls. It gives some idea of the alternations which occur in the strata. In a total height of 250 feet (165 feet at the Falls, at F, on the right) there are, on the left, six different strata in view, and parts of two others, the upper and lower, making eight in all. Number 1 is gray argillaceous sandstone; 2, gray and red argillaceous sandstone and shale; 3, flagstone, or hard laminated sandstone; 4, reddish shale and shaly sandstone; 5, shale; 6, limestone; 7, shale; 8, limestone. Only two of these strata, 7 and 8, are in sight at the Falls (at F). The alternations are thus numerous and various in all regions of stratified rocks. Along the cañon of the Colorado there are in some places more than 8,000 feet of stratified beds, showing their edges in lofty precipices, and in the mountains towering above the adjoining plains.

It must not be inferred that the earth is covered by a regular series of coats, the same in all countries; for this is far from the truth. Many strata occur in New York that are not found in Ohio and the States west, and many in South-

ern New York that are not in Northern; and each stratum varies greatly in different regions, sometimes being limestone in one and sandstone or shale in another.

A *stratum* is a bed of rock including all of any one kind that lie together, as either Nos. 1, 2, 3, 4, 5, 6, 7, or 8 in the preceding figure.

A *layer* is one of the subdivisions of a stratum. A stratum may consist of an indefinite number of *layers*.

A *system* includes all the various kinds of strata that were formed in one age or period, as the Carboniferous system or that of the coal era. A subdivision of a system, including two or more related strata, is often called a *series*, or a *group*.

2. Unstratified condition. — Unstratified rocks are those which do not lie in beds or strata. Mountain-masses of granite are often without any appearance of stratification. The rock of the Palisades, on the Hudson, stands up with a bold columnar front, and has no division into layers. Most lavas of volcanoes have flowed out in successive streams; and, consequently, volcanic mountains are generally stratified. But in some volcanic regions the rocks rise into lofty summits without stratification. Although true granite bears no marks of proper stratification, it very often passes insensibly into gneiss, which is a stratified rock; and there is evidence in this fact that granite is often a stratified rock which has lost the appearance of stratification in consequence of the crystallization it has undergone.

3. Vein-form condition. — When rocks have been fractured, and the fissures thus made have been filled with rock-material of any kind, or with metallic ores, the fillings are *vein-form*, and called *veins*. Veins are large or small, deep or shallow, single or like a complete network, according to the character of the fractures in which they were formed. They may be as thin as paper, or they may be rods in width. Figs. 15 to 18 represent some of the forms. In Fig. 15 there are two veins, *a* and *b*; in Fig. 16, a network of thin veins; in Fig. 17, two, *a*, *d*, of very irregular form,—a kind not uncom-

mon, and another, *b*, intersecting one of these; in Fig. 18, two large veins, of still more irregular character cross one another.

Fig. 15.

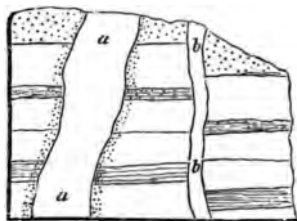


Fig. 16.

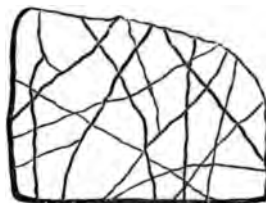


Fig. 17.

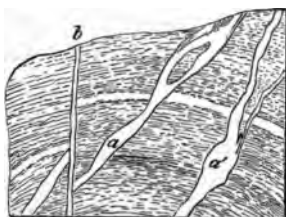


Fig. 18.

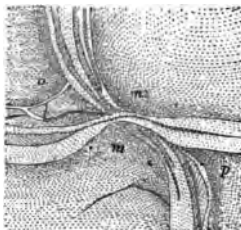


Fig. 19.

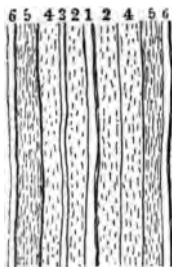
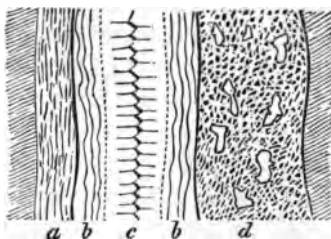


Fig. 20.



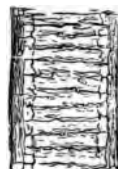
Many veins have a *banded* structure, like Figs. 19 and 20.

Many metallic veins are thus banded, and have the ores lying in one or more bands alternating with other stony bands consisting of different minerals or rock-material, as *pyrite*, *quartz*, *fluorite*, etc., called the *gangue* of the ore.

In Fig. 20, representing a Cornwall lode, the middle portion, *b c b*, is made up of bands of agate, *b*, with two layers of crystallized quartz, *c*, at centre; *a* is a layer of quartz; *b*, a band of the copper ore of the vein, chalcopyrite (copper pyrites); *d*, quartz with some fluorite.

Fig. 21.

When fissures have been filled with *melted rock*, they are usually called *dikes*; they have regular walls, and are not banded, although sometimes the sides differ a little from the middle. They are often transversely columnar in structure, as is illustrated in Fig. 21.



4. Relation of stratified and true unstratified rocks in the earth's crust. — The relations of the stratified and unstratified rocks in the earth's crust will be understood after considering the origin of the crust.

The crust is believed to be the cooled exterior of a melted globe. After the solidifying of the sphere at surface, the ocean commenced at once to make *fragmental stratified* rocks over the exterior through the wear of the crust-rocks, and the stratifying of the sand or mud thus made; while the continued cooling, going on very slowly, made *unstratified* rocks beneath this first crust as its inner portion. The ocean thus worked over and covered up with strata nearly all, *if not all*, the original unstratified crystalline rocks. Hence the areas of the unstratified rocks that were made in the first solidification of the globe are of very small extent over the continents, if visible anywhere.

Geology has, for its study, chiefly stratified rocks. Much the larger part of all the facts in geological history are derived from rocks of this kind, and therefore the various details with regard to their structure and arrangement are of the highest importance.

Stratified Condition.

I. Structure.

1. **Massive, laminated, and shaly structures.**—The massive (Fig. 22, *a*), laminated (Fig. 22, *b*), and shaly (Fig. 22, *c*), structures of layers have been explained on page 32. Sandstone is in general most perfectly laminated when argillaceous, or containing much *clay* or *fine earthy material*. The same is true of limestone. The flagging stone used in most Eastern cities for walks, is an example of a *laminated sandstone*, and of *flags*. It is from near Kingston, N. Y., and other places on the west side of the Hudson.

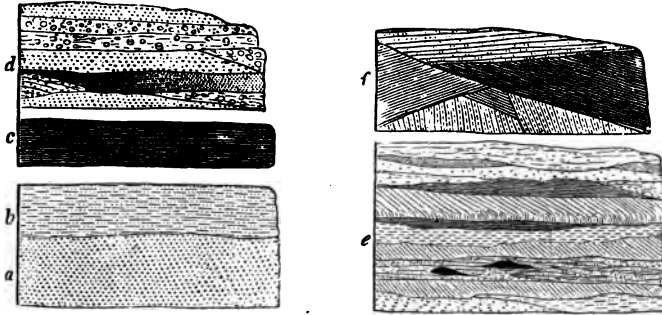
2. **Stratulate structure.**—The layers of a rock, as clays, shales, sand-beds, sandstones, limestones, are often themselves stratified in a very thin manner, and while the thin laminae separate easily in some cases (as in many clay-beds and shales), they are indicated in others only by the banded appearance of a surface of transverse fracture. The structure is *stratulate*. Only when the little layers are separable is the structure *laminated*.

3. **Beach structure.**—The structure of the upper part of a beach is illustrated in Fig. 22, *d*. Instead of being composed of evenly laid material, it consists of many irregular small layers as deposited or thrown together by the waves during storms. The lower part of the beach has an even slope of usually 5 to 15 degrees, and the sands beneath are in beds having the same slope.

4. **Cross-bedded structure.**—In Fig. 22, *e*, the beds that are *obliquely stratulated* or *laminated* are examples of the cross-bedded structure. Such beds, which have sometimes great extent, have resulted from the pushing along of the bottom sands or earth by currents, causing at first a little elevation or ridgelet, and then depositions successively over the front or down-stream slope of the elevation. They alternate with

other layers that are horizontal in bedding, because the inflowing tide alternates with the outflowing, or because, if of fresh-water origin, such streams vary in flow from low water

Fig. 22.



to high. The succession of beds in Fig. *e* has been described as the *ebb-and-flow* structure. It is common in stratified drift as a result of river floods.

5. **Flow-and-plunge structure.**—Where the waves plunge heavily in connection with a flow of tidal or other currents, the obliquely laminated layer is broken up into wave-like or wedge-shaped parts, a few feet or yards long, as illustrated in Fig. 23. This structure is common in stratified drift.

Fig. 23.



6. **Quaquaversal or Wind-drift structure.**—Having the subordinate layers dipping in various directions, sometimes curving and sometimes straight, as shown in Fig. 22, *f*. The hills of sand formed by the winds (as on a sea-coast or the shores of large lakes) are usually thus stratified. The sands drifted over the rising heaps form layers conforming to the outer surface, and so may slope at all angles. In storms, the heaps may be blown away in part, and afterward be completed

again; but the new layers will conform to the new outer surface, and hence have a different direction. In this way, by successive destructions and re-completions, a bed of sand may be made which shall consist of parts sloping in one direction and other parts in directions very different, with numerous abrupt transitions, as illustrated in the figure.

Fig. 24.

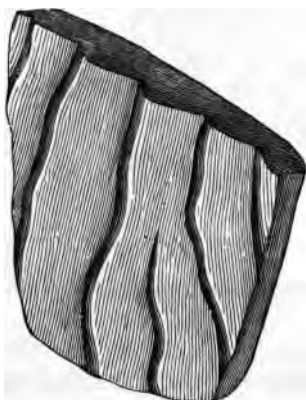
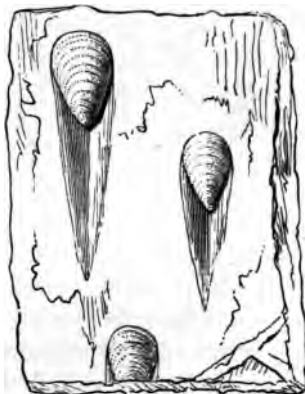


Fig. 25.



7. **Ripple-marks.**—A gentle flow of water, or its vibration, over mud or sand, ripples the surface. The lighter winds also make ripples over fields of sand. Layers of sandstone and clayey rocks are often covered with ripple-marks (Fig. 24).

8. **Rill-marks.**—When the waters of a spreading or returning wave on a gently sloping beach pass by shells or stones lodged in the sand, the rills furrow out little channels. Fig. 25 shows such rill-marks alongside of shells (*Lingulæ*) in a Silurian sandstone.

9. **Mud-cracks, earth-cracks.**—When a mud-flat is exposed to the air or sun to dry, it becomes cracked to a few inches or feet in depth. Fig. 26 represents mud-cracks in argillaceous sandstone. Such cracks may subsequently become filled with stony material, either sediment or material in solution; and

as such fillings are often made harder than the rock itself they may stand as prominent ridges above a weathered surface of the rock. It is actually a network of veins, but of very shallow veins that were filled from above. In regions of long droughts, the earth-cracks over prairies and alluvial flats are sometimes many and deep, and over a foot wide.

Fig. 26.

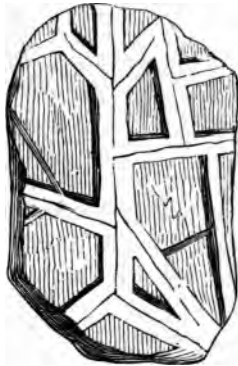
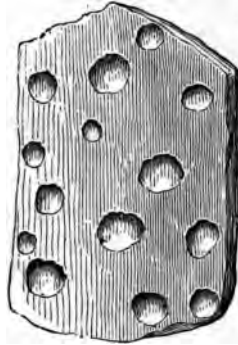


Fig. 27.



10. **Rain-prints** (Fig. 27).—The impressions of the large rain-drops of a short shower made on a half-dry mud, have often been preserved in the rocks.

11. **Concretionary structure.**—Layers often contain small spheres or disks of rock, which are called *concretions*. They result from a tendency in matter to concrete or solidify around centres. Some are no larger than grains of sand, or the roe of fish, as in *oolitic* limestone (page 37). Others are as large as peas or bullets, and others a foot or more in diameter.

Fig. 28.



Fig. 28 represents a spherical concretion; Fig. 29 a rock made up of rounded concretions, having a concentric structure; Fig. 30, one with flattened or disk-shaped concretions.

Concretions are usually *spherical* in massive sandstones. *lenticular* in laminated sandstones or clays, and *flattened disks*

in argillaceous rocks or shales. All these kinds are shown in Fig. 31. The balls are sometimes hollow, and the disks mere rings. Frequently the concretions have a shell or other organic object at centre (Fig. 32). They are often cracked

Fig. 29.

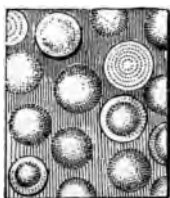


Fig. 30.

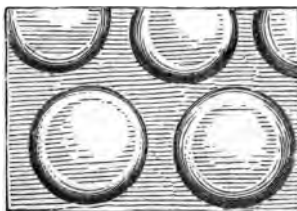
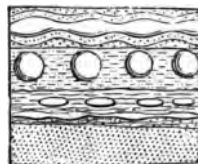


Fig. 31.



through the interior (Fig 33) from drying (some soft clayey muds contracting to a tenth of their bulk); the outside in such a case solidified while the inside was still moist. The cracks may afterward become filled with other minerals.

Fig. 32.



Fig. 33.

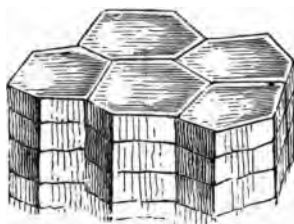


Fig. 34.



Sometimes they contain a loose ball within, — a concretion within a concretion. A cavity lined with crystals (Fig. 34) is called a *geode*. But the hollow balls so lined within are not generally true concretions.

Fig. 35.



12. Columnar forms from contraction. — a more or less perfect columnar structure, due to contraction on cooling, is exemplified often by igneous rocks, as represented in Fig. 35 and Fig. 119, of page 145. The columns have frequently transverse fractures, but the fractures are usually less

regular than in the preceding figure; in many cases the top of the sections of a column is concave upward, but often flat and sometimes convex. The structure is sometimes found in sandstone that has been heated, but generally the fracturing so produced is very irregular.

13. **Jointed structure.** — The rocks of a region are often divided very regularly by numerous *straight planes of fracture*, the most of them *parallel* to one another, and cutting through vertically or at large angles to *great depths*. Such deep planes of fracture may characterize the rocks over areas hundreds of miles in extent. They are called *joints*; and a rock thus divided is said to present a *jointed structure*. In many cases there are two systems of joints or divisional planes in the

Fig. 36.



same region, crossing one another, and the undermining of a bluff of jointed beds and tumbling down of masses leads to the production of forms like those of fortifications or broken walls, as shown in Fig. 36, — representing a view on the shores of Cayuga Lake. The directions of such joints are facts which the geologist notes down with care.

14. **Slaty cleavage.** — The term *slaty* has been explained on page 33. But one important fact, not there stated, is that the slates are often *transverse to the bedding*, that is, they often cross the layers of stratification more or less obliquely, instead of conforming to the layers or bedding like the *shaly* structure. Slaty cleavage is in this respect like the jointed structure; but it has the planes of fracture or divisional

planes so numerous that the rock divides into slates instead of blocks; and the two differ in mode of origin. Slaty cleavage is confined to fine-grained rocks. In Fig. 37 the lines of bedding or stratification are shown at *a*, *b*, *c*, *d*, while the

Fig. 37.

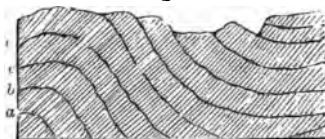


Fig. 38.



transverse lines correspond to the direction of the slates. The same is shown in Fig. 38 with the addition of a slight irregularity in the slates along the junction of two layers.

2. Positions of Strata.

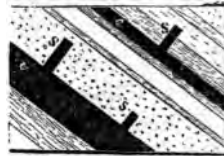
1. Original position of strata. — Horizontal position. — Ordinary stratified rocks were once beds of sand or earth, or of other rock-material, spread out by the currents and waves of the ocean, or the waters of lakes or rivers, or by the winds.

When the larger portion of the beds over the North American continent were formed, the continent lay to a great extent beneath the ocean, as the bottom of a great, though mostly shallow, continental sea. The principal mountain-chains — the Rocky Mountains and the Appalachians — had not yet been made, and the surface of the submerged land was nearly flat. The fact (1) that those beds were really *marine* is proved by their containing, in most cases, *marine* shells, crinoids, or corals, the relics of marine life; and (2) that the continental seas had great extent, by the fact that the beds cover surfaces tens of thousands of square miles in area, some of them reaching from the Atlantic border westward beyond the Mississippi. In the large continental seas, the deposits made by means of the currents and waves were nearly or quite *horizontal*. As they increased, they would near

the surface; and here the action of the waves would tend to chisel off and keep level the upper surface of the beds, whether accumulations of sand or earth, or of shells or corals. If the bottom over the region were very slowly sinking, the accumulations might go on thickening, and the beds continue to have the same level or *horizontal* position. Strata formed along the borders of rivers and lakes have horizontal beds, and so have those on the borders of the ocean; and for a like reason, that the water works through, or with a reference to, its surface, which is horizontal. Moreover, the bottom of the border of the Atlantic, south of Long Island, is (see Fig. 3, p. 12), for eighty miles from the coast-line, so nearly horizontal that it deepens only 1 foot for every 600 to 700; and if the area were above the ocean, no eye would detect that it was not perfectly level.

Other beds were originally vast marshes, like the marshes of the present day, only larger. Such was the condition of the beds in the coal-formation that are now coal. Many coal-beds contain stumps of trees rising out of the coal (Fig. 39); and they always stand *vertically* on the bed, however much the latter may be displaced, showing that the bed was horizontal when it was formed, or when the trees were growing.

Fig. 39.



Exceptions to a horizontal position. — When a river empties into a lake or sea, the bottom of which, near its mouth, is more or less inclined, the deposits of detritus made by the

Fig. 40.



river will for a while conform to the slope of the bottom, as in Fig. 40. When rivers fall down precipices, they make

a steep bank of earth at the foot, whose layers, if any are made, have the slope of the bank. In beach-made deposits the layers have the slope of the beach (page 44). But these and similar cases of exceptions to a horizontal position are of small extent.

2. **Dislocations of strata.** — Most of the strata of the globe have lost their original horizontal position so as to be more or less inclined; and some are even vertical. They are occasionally bent or folded, as a quire of paper might be folded, only the folds are miles, or scores of miles, in sweep.

They have often also been fractured, and the separated parts have been pushed, or else have fallen, out of their former connections, so that the portion of a stratum on one side of a fracture is often inches, feet, or even miles, above that on the other side.

It is stated on page 1, that a thickness of rock equal to 18 or 20 miles is open to the geological explorer. This could not be true were all strata in their original horizontal position; for in that case the most that would be within reach would not exceed the height of the highest mountain. But the upturning which the earth's crust has undergone has brought the edges of strata to the surface, and there is hence no such limit: however deep stratified beds may extend, there is no reason why the whole should not be brought up so as to be exposed to view in some parts of the earth's surface.

The following are explanations of the terms used in describing the positions of strata:—

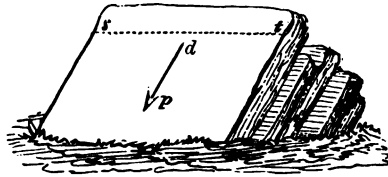
1. *Outcrop.* — The portions or ledges of strata projecting out of the ground, or in view at the surface (Fig. 41).

2. *Dip.* — The angle of slope of inclined or *tilted* strata. In Figs. 41, 42, *d p* is the direction of the dip. Both the *angle* of slope and the *direction* are noted by the geologist: thus, it may be said of beds, the dip is 50° to the south, or 45° to the northwest, etc.

When only the edges of layers are exposed to view, it is

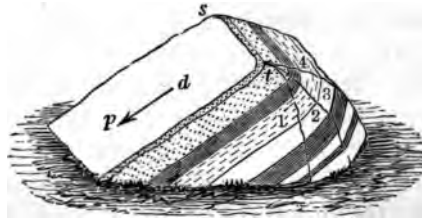
not safe to take the slope of the edges as the slope of the layers; for in Fig. 42 the edges on the faces 1, 2, 3, 4 are

Fig. 41.



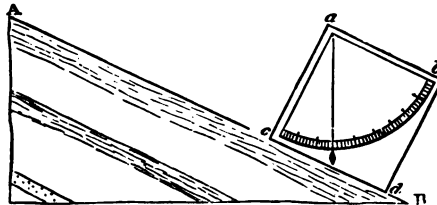
all edges of the same beds, and only those of the face 1 would give the right dip.

Fig. 42.



The *dip* is measured by means of instruments called *clinometers*. In Fig. 43, *a b c d* represents a square block of

Fig. 43.

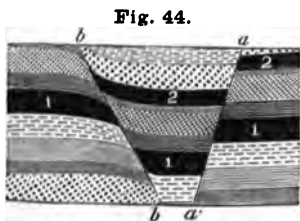


wood, having a graduated arc *b c* and a plummet hung below *a*. Placed on the sloping surface *A B*, the position

of the plummet gives the angle of dip. This kind of clinometer is often made in the form of a watch and combined with a compass. It is most convenient for use when it has a square base. One like that figured is easily made out of a piece of board; it may be 3 to 4 inches on a side, and half an inch or so thick. To avoid errors from the unevenness of a rock, a board should be laid down first and the measurement be made on its surface. But if the instrument has a square base it is often best to measure the dip by holding it between the eye and the rock, with one edge of the base in the direction of the dipping layers.

3. Strike.—The *horizontal* direction at right angles with the dip. In Fig. 41, the dotted line st represents the direction of the strike. It is measured by means of a small compass which usually forms part of the clinometer. Such a compass may be set in a clinometer made like the above figure (Fig. 43). It need not be central in the square, but should have the meridian line parallel to one of the four sides. If the edges of the layers in view over a ledge are in any part *quite horizontal*, the direction of those edges will give the true strike; but if they are at all inclined, a horizontal line should be drawn, if possible, on the surface of one of the layers. The clinometer may be used also for measuring the dip of rocks that are rods distant, and the slopes of distant mountains.

4. Fault.—In the making of faults (aa , bb , Fig. 44) there

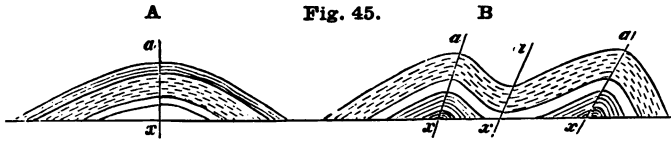


is *first* a fracturing, and then a shoving up or down of the beds on one side of the fracture; that is, a *downthrow* on one side or an *upthrow* on the other. The amount of displacement is the amount of fault; it may be a foot or less, or 10,000 feet or more.

In Fig. 17, on page 42, the vein a is faulted along the line of b . The friction attending the downthrow may cause a

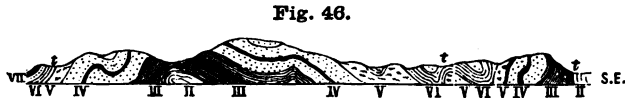
bending of the layers in contact, as along the line *bb*, in Fig. 44. The deepest fractures and faults have been produced in connection with the making of mountains.

5. *Folds or flexures.* — Folds or flexures in strata are represented in the following sections; Fig. 45, A, B, and in the nat-



ural section, Fig. 46, from the Appalachian Mountains, a region of numerous flexures on a grand scale, as well as of many faults; some flexures having a span of several miles, and others of only a few feet or inches.

In Fig. 45, *a x* is the *axis* or axial plane of the fold.

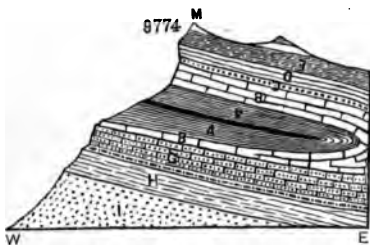


The flexure very often has one side steeper than the other, as illustrated above. In some regions the push by which they were made was continued until the fold became vertical; and, further still, until the top was pressed over beyond the vertical, and fold of this kind followed fold, as illustrated in Fig. 47. In more extreme cases the push has continued until there has been produced a complete overturn or inversion of the beds, as is represented in the following section



(by Renevier) from the Alps east of the Rhone, the whole height of which is 6,500 feet. The bed A, which before the folding was the uppermost stratum is folded back on itself for more than three miles; and B, C, D, E, which

Fig. 48.



Section West to East. — A, upper Eocene; B, Nummulitic bed, or lower Eocene; C, D, E, Cretaceous (E. Neocomian); G, Jurassic limestone; H, Carboniferous; I, Metamorphic; M, Dent de Morcles.

were originally underlying strata, now overlie it, upside down. It is seen that the strata C, D, E are present only in the overturned part of the fold; these beds must have covered G to the westward and not to the eastward.

Flexures often have fractures somewhere along the bend; and the fractures are often lines of faults.

6. Anticline. — An *upward* bend in the strata, sloping *away* from a common plane in opposite directions, as the layers either side of ax in Fig. 45 A: the axis is here called an *anticlinal axis*. The word *anticline* is from the Greek *ἀντί*, *in opposite directions*, and *κλίνω*, *I incline*.

7. Syncline. — A *downward* bend, the strata sloping *toward* a common plane. In Fig. 45 B, ax , $a'x'$ are *anticlinal axes*, $a'x'$, between the others, a *synclinal axis*. The word *syncline* is from the Greek *σύν*, *together*, and *κλίνω*.

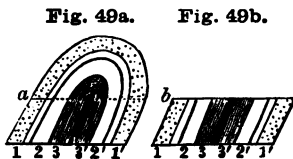
8. Monocline. — Having the strata sloping in only one direction, as when strata are fractured and those of one side are lifted along the fracture. The word *monocline* is from the Greek *μόνος*, *one*, and *κλίνω*.

9. Geanticline, Geosyncline. — Bendings of the earth's crust, *geanticline* an upward bend, and *geosyncline* a downward bend. These words are from the Greek for *earth* and the words *anticline* and *syncline*.

In ordinary synclines and anticlines the flexures are those of the strata which overlie the earth's crust. The bendings of the earth's crust are necessarily of very small angle and broad span, on account of its thickness; one of 10° in a crust 25 miles thick with a span of only 25 miles is not to be looked for.

The subject of flexures and faults is best studied by making models out of sheets of moist clay (or better of paraffine containing a little beeswax), using lampblack and red and yellow ochre for coloring the different beds, and then making cross-sections.

10. Effects of denudation on Flexed or Upturned Rocks; Decapitated Folds. — If the top of the fold in Fig. 49 a were cut off at *a b*, there would remain the part represented in Fig. 49 b, in which there is no appearance of any fold, and only a uniform series of dips; and although 1', 2', 3' appear to be the *lower* strata of the series, they are actually parts of 1, 2, 3.



A long series of such folds pressed together, and then decapitated, would make a series of uniform dips over a wide extent of country, obscuring wholly the true stratification.

This obscuring of the true succession has been greatly increased by the removal of the beds over great areas and the filling up of intermediate depressions by soil: so that the

Fig. 50.



rocks are visible only at long intervals (as in Fig. 50). Many of the difficulties in the study of rocks arise from this cause.

11. Unconformable strata. — When strata have been tilted, or folded, and, subsequently, horizontal beds have been laid

Fig. 51.



down over them, the two sets are said to be *unconformable* because *they do not conform in dip*. It is a case of *unconformability* in the stratification. Thus, in Fig. 51 the beds

a b are unconformable to those below them; so also the tilted beds *c d* are unconformable to those beneath, and the beds *e f* to the beds *c d*.

It is plain that the folded rocks represented in Fig. 51 are the oldest, and that the folding took place before the overlying beds were deposited. Again, it is evident that the beds below the line *c d* are older than the beds between *c d* and *e f*, and also that they were tilted and faulted before the latter were formed. Supposing the *underlying* folded or upturned rocks were those of the Alps: if the upper of them were of the age of the Chalk (the Cretaceous period) and contained marine fossils, showing them to be of marine origin, and the unconformably overlying beds belonged to some division of the Tertiary, the geologist would conclude that the upturning, in which the mountains were lifted above the sea, occurred after the period of the Chalk, and before that to which the Tertiary beds belonged. Or, if the latest underlying marine beds were of the 1st period of the Tertiary, and the overlying of the 2nd period, then the time of uplift would be more narrowly determined as directly following the first of these periods. These examples illustrate the importance to geology of observations on unconformability in stratification.

Unconformability of overlap is a kind in which there is scarcely any appreciable unconformability in dip, and no upturning was concerned. It exists when the sea of one era, after depositing horizontal beds, has, in the following era, spread far over the land and has deposited another series of beds with these new limits. These changes of sea-level were going forward during the progress of most formations, and, consequently, unconformability through overlap should be common, though not always easily distinguished.

3. Order of Arrangement of Strata.

It has been explained that the strata are historical records as to the past conditions of the earth's surface. In order

that the records may make an intelligible history, there must be some way of arranging them in their proper order, that is, *in the order of time*. The determination of this *order* is one of the first things before the geologist in his examinations of a country.

Many difficulties are encountered.

1. The strata of the same period or time — called *equivalent strata*, because approximately equivalent in age — differ, even on the same continent. Sandstones and shales were often forming along the Appalachians in Pennsylvania and Virginia, when limestones were in progress over the Mississippi Valley. The chalk-formation in England contains thick strata of chalk; but in Eastern North America the same formation exists without any chalk.

2. When rocks have been forming in one region, there have been none in progress in many others. Hence the series of strata serving as records of geological events is nowhere perfect. In one country one part may be very complete; in another, another part; and all have their long blanks,— that is, large parts of the series entirely wanting. In New York and the States west to the Mississippi, there is only part of the lower half of the series. In New Jersey there is part of the lower half and part of the upper half, with wide breaks between. Over a large part of Northern New York there exist only the very earliest of rocks.

The thickness of the fossiliferous series in the State of New York, south of its centre, is about 13,000 feet, and north of its centre they thin out to a few feet; in Pennsylvania, the thickness is about 30,000 feet (Lesley); in Indiana and other adjoining States west and south, 3,500 to 6,000 feet. In Great Britain, the whole thickness above the unfossiliferous bottom-rocks is over 100,000 feet.

3. The rocks of a country are to a great extent covered with earth or soil, so that they can be examined only at distant points.

4. The strata, in many regions, have been displaced,

folded, fractured, faulted, and even crystallized extensively, adding greatly to the difficulties in the way of the geological explorer.

The following are the methods to be used in determining the true order of arrangement:—

A. In sections of the rocks exposed to view in the sides of valleys or ridges, the order should be directly studied, and each stratum traced, as far as possible, through all the exposed sections.

When, through large intervals, a covering of soil or water prevents the tracing of the beds, other means must be used.

B. The aspect or composition of the rock may help to determine which strata are identical. But this method should be used with great caution, for the reason stated above, in § 1,—that rocks made at the very same time may be widely different; and, conversely, those made in very different periods may look precisely alike in color and texture.

C. Fossils afford the best means of determining identity. This is so because of the fact, already mentioned, that the fossils of an epoch are very similar in genera—if not also in species—the world over; and those of different epochs are different in these respects. The geologist, by studying the fossils of the several beds at any locality, learns which kinds are characteristic of each bed, and the order of succession. Then, by comparing the beds of different localities, he ascertains whether any are essentially alike in species, and therefore of like age or period, and from this determination continues further his study of the order of succession. By pursuing this course, for all accessible localities over a country, and different countries, geologists have ascertained the characteristic kinds of fossils for the successive strata through the long series of formations; and the lists which have been thus made serve for the identification of strata in widely distant regions. By a comparison of fossils it was proved that the chalk-formation exists in Eastern North America, although there is no chalk to be found there. In the same

manner, the equivalents in America of the principal subdivisions of the rock series of Britain and Europe, Asia, and even Australia, are approximately ascertained; for this means of determination is a universal one, applying to the equivalency of rocks in different hemispheres as well as those on the same continent.

This method has its *doubts*. These doubts arise (1) from the fact that one continent may have received part of its species from another long after their first appearance on that other; and, (2) from another fact, that the exterminations of species which have taken place at the close of a period may have been far more complete in one region than another, so that certain species were living long in one after their disappearance from the other. Again, there are doubts arising (3) from the fact that, in any period, the life of one locality is very different from that of another, on account of differences in purity of waters, muddy or rocky bottom, and temperature. The removal of all doubts, especially with respect to the minor subdivisions of the geological series on different continents, or distant parts of the same continent, is not to be looked for. Yet, by proceeding with care, and using not isolated facts, but the whole range afforded by the fossils, animal as well as vegetable, the general order of succession may be made out for each country, if not the precise parallelism for different countries.

PART III.

DYNAMICAL GEOLOGY.

DYNAMICAL GEOLOGY treats of the *causes or origin* of events in geological history, — that is, of the *origin* of rocks, of disturbances of the earth's strata and the accompanying effects, of valleys, of mountains, of continents, and of the changes in the earth's features, climates, and living species. The agencies of most importance, next to the universal power of *Gravitation* and *Cohesive* and *Chemical* attraction, are *Life*, the *Atmosphere*, *Water*, and *Heat*.

The following are the subdivisions of the subject here adopted: 1. *Life*; 2. *The Chemical action of the Atmosphere and Waters*; 3. *Mechanical effects of the Atmosphere*; 4. *Mechanical effects of Water*; 5. *Action of Heat*; 6. *Movements in the earth's crust, and their consequences*, including the folding and uplifting of strata, and the origin of mountains and of the earth's general features.

I. — LIFE.

A. Formative Effects.

Life has done much geological work by *contributing material* for the making of rocks. Nearly all the limestones of the globe, all the coal, and some siliceous beds, besides por-

tions of rocks of other kinds, have been formed out of the stony relics of living species. Both animals and plants have been large sources of the material. The skeletons or stony secretions of animals, after fulfilling the purposes of life, have been turned over to the mineral kingdom, to be made into minerals and rocks. Similarly, from vegetable structures have come beds of stone as well as beds of coal.

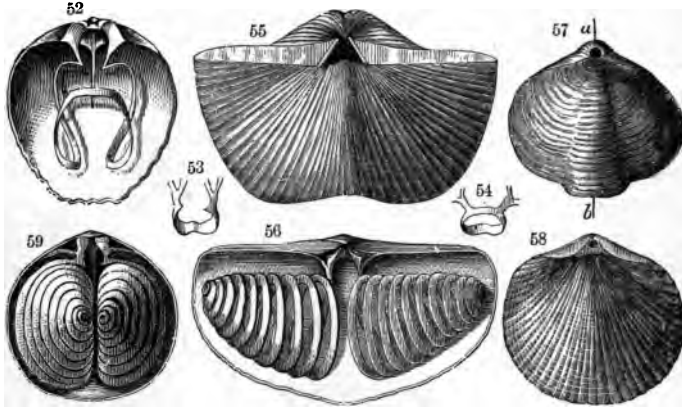
1. KINDS AND SOURCES OF ORGANIC MATERIALS.

A. Calcareous material, or that of which limestones consist, has been derived chiefly from the following sources.

1. **SHELLS OF MOLLUSKS.**—These include:

(1.) The ordinary bivalve shells, like the oyster and clam (described on page 182 as Lamellibranch Mollusks).

Figs. 52-59, BRACHIOPOD MOLLUSKS.



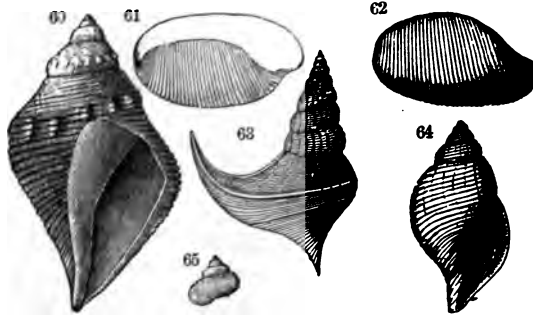
BRACHIOPODS.—Fig. 52, *Waldheimia flavescens*, interior view; 53, loop of *Terebratula vitrea*; 54, id. *Terebratulina caput-serpentis*; 55, *Spirifer striatus*; 56, same, interior of dorsal valve; 57, *Athyris concentrica*; 58, 59, *Atrypa reticularis*, the latter dorsal valve.

(2.) Other bivalve shells (those of Brachiopod Mollusks) having symmetrical forms, as illustrated in Figs. 52 to 59. Figs. 52, 56, 59 show the characters of the interior of

the shells. In ancient time the shells of this tribe exceeded all others in abundance, but now they are relatively few.

(3.) The univalves (shells of Gasteropod Mollusks), having commonly spiral forms: like the snail and the kinds represented in Figs. 60 to 65.

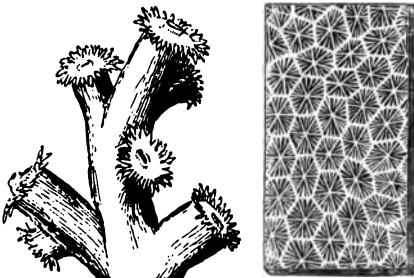
Figs. 60-65.



GASTEROPODS.— Fig. 60, *Pyrisus Newberryi*; 61, 62, *Bulla speciosa*; 63, *Anchura (Drepanochellus) Americana*; 64, *Fasciolaria buccinoides*; 65, *Margarita Nebrascensis*.

(4.) Other species (Cephalopods) some of which are represented in Figs. 347–351, on page 298. Besides these there are still others (Bryozoans) which make small coral-like and encrusting forms, illustrated on page 181.

Figs. 66, 67, CORALS.

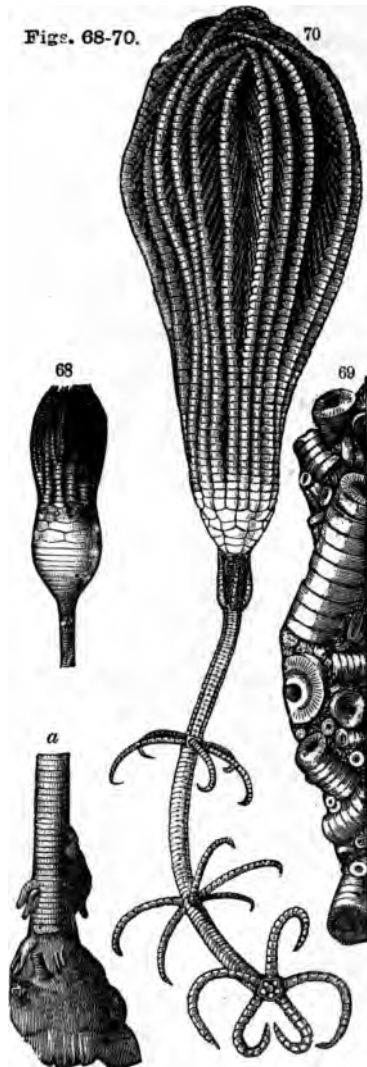


2. CORALS (Figs. 66, 67). — The stony secretions, mainly of Polyps. They contributed largely to the older rocks of the world and are still making great limestone formations. Fig. 66 represents a living coral, and 67, a fossil species.

There are also *Millepore* or *Hydroid Corals* (page 184) among the limestone-making species.

3. CRINOIDS. — Species of Echinoderms (page 184) having radiating arms above, about the mouth, and a stem usually, for attachment, the whole made of small calcareous pieces. Some limestones were formed chiefly from remains of Crinoids. Of the three figures given, 68 represents an ancient kind (reduced), and 70 is a living Atlantic species (natural size), from Wyville Thomson's "Depths of the Sea," — a kind that plants itself in the mud of the sea-bottom by means of the appendages at the base of the stem, instead of being firmly attached or rooted. Fig. 69 represents a portion of a mass of ancient limestone made up of fragments of the stems of crinoids. The few existing species occur in the ocean at various depths to 2435 fathoms, but are most common between 80 and 400 fathoms.

4. FORAMINIFERS OR CALCAREOUS SHELLS OF RHIZOPODS. — These shells (Figs. 71–84) are mostly very small, and yet through their abundance they have been very im-



CRINOIDS: Fig. 68, *Aptocrinus Roysianus* (a, lower part of stem); 69, portion of a mass of crinoidal limestone; 70, *Pentacrinus Wyville-Thomsoni*.

portant in limestone-making. In size they are generally between a grain of sand, and an eighth of an inch; but Figs. 83 and 84 are of natural size, and still larger occur. They are all marine, the fresh-water species not having calcareous

Figs. 71-84, FORAMINIFERS, OR SHELLS OF RHIZOPODS.

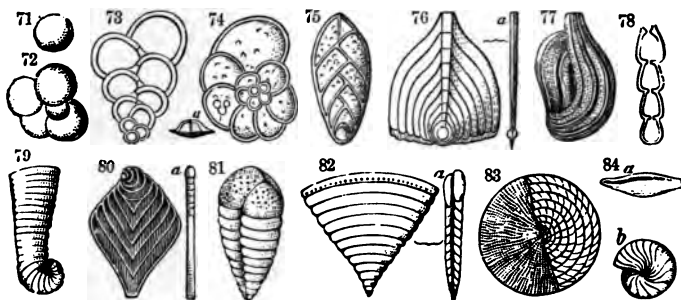


Fig. 71 *Orbulina universa* · 72, *Globigerina rubra* · 73, *Textilaria globulosa*, Ehr.; 74, *Rotalia globulosa* · 74 a, Side-view of *Rotalia Boucana*; 75, *Graniostomum phylloides* Ehr.; 76, *Fronidularia annularis*; 77, *Triloculina Josephina*; 78, *Nodosaria vulgaris*; 79, *Lituola nautiloides*; 80 a, *Flabellina rugosa* · 81, *Chrysalidina gradata*; 82 a, *Cuneolina Pavonia*; 83, *Nummulites nummularia*; 84 a, b, *Fusulina cylindrica*.

shells. Some kinds belong especially to the border region of the ocean (*Textularias*, *Rotularias*, *Nodosarias*, etc.), while others (*Globigerinas*, Fig. 72 etc., and Fig. 171, page 185) belong to the open sea, or are pelagic kinds. The latter often make the fine mud or ooze of the sea-bottom in latitudes inside of 60°, constituting what is called the *Globigerina ooze*. The chalk was made mainly of such materials.

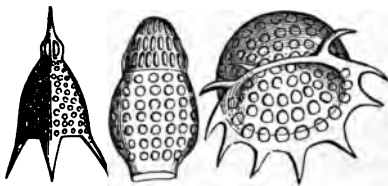
5. SOME MARINE PLANTS, as (1) the *Nullipores*, which look like corals but have no cells — whence the name signifying *no pores*; (2) the *Corallines*, which are delicate, semi-calcareous sea-plants; (3) *Coccoliths*, minute stony disks of a one-celled sea-plant (named from *κόκκος*, *seed*), and the related *Rhabdoliths* which are rod-like in shape.

B. Siliceous material of organic origin is far less abundant than calcareous; for quartz is mostly from mineral sources.

1. ANIMAL IN ORIGIN. — (1.) Many *Sponges* afford siliceous spicules. The forms of some of the spicules are shown in Figs. 250, 251, on page 234, and their fragments, among the Diatoms in the figure on page 68. The horny fibres which make up a sponge constitute the skeleton of a multitudinous group of minute sponge-animals which are somewhat related to the Rhizopods. The spicules, when present, occur within these fibres and often bristle their surface. (In some sponges they are calcareous.) Other sponges, like that of Fig. 374, page 314, have the whole skeleton of silica; and these, which are called *glass* or *vitreous* sponges, grow over the ocean's bottom at various depths, but most abundantly between 90 and 100 fathoms.

(2.) The *Radiolarians* (Figs. 85–87) are marine Rhizopods having *siliceous* shells (often lacework-like), which are usually symmetrical about the centre or central line, and sometimes spherical. The name is from the Latin for *radial*. Another kind is represented on page 186. They live in all zones. The Challenger expedition found a "Radiolarian ooze" at depths between 11,000 and 23,000 feet.

Figs. 85-87, RADIOLARIANS.



2. VEGETABLE IN ORIGIN.— Minute plants, called *Diatoms* (from two Greek words referring to a *subdivision* which takes place in the process of reproduction), have siliceous shells. Some kinds are represented (part of them broken) in Fig. 88; they are from an earthy deposit near Richmond in Virginia. They grow so abundantly in both fresh and salt waters that they make thick chalk-like deposits, and those of the deep ocean, between 6,000 and 12,000 feet, are very extensive. They live near the surface, and in certain parts of the ocean, the Polar seas included, they often tint the

water, and are sometimes massed together, they are so abundant. Many sea-animals live on them. The flint, chert and jasper, which form nodules and sometimes layers in lime-

Fig. 88, DIATOMS.



stone and other rocks, have been made largely from spicules of Sponges, or the shells of Radiolarians or Diatoms.

C. Phosphatic material, chiefly Calcium phosphate. — Vertebrate animals (Fishes, Amphibians, Reptiles, Birds, and Mammals or Quadrupeds) have contributed very little calcareous material to the rocks, compared with inferior tribes of animals. But they have been an important source of *phosphate* salts, and the deposits are often worked because the material

is valuable as a fertilizer. Bones, scales, and, to some extent, all animal tissues of vertebrates and invertebrates contain phosphatic material. The mineral apatite, common in many crystalline limestones, is a calcium phosphate, and has sometimes had this source. Guano, which owes its value largely to its phosphates, has been made chiefly from the excrements of birds in *dry* regions where the birds long had undisturbed possession; as on some small coral islands in the Central Pacific, islands off the Peruvian coast, the coast of equatorial Africa, and in the Caribbean Sea.

Coprolites, or isolated excrements of reptiles and fishes, and sometimes of other animals, occur in many rocks. Vegetable tissues also afford phosphates, 100 parts of the ashes of ordinary meadow grass affording 8 parts of phosphoric acid; of rye-straw, 4 parts; of clover, 18 parts; of seaweeds, 1 to 5 parts.

The shells of certain Brachiopods — the *Lingula* and some

related species — are largely phosphatic. These shells and the shells of Crustaceans when fossilized are usually black, because of the large amount of animal matter they contain, this portion becoming carbonized.

D. Carbonaceous material. — The most abundant contributions from the vegetable kingdom to rocks are the beds of *mineral coal*, coal being made from woody tissues. Mineral oil has in part the same source, and partly is of animal origin. *Graphite*, which is pure carbon, is often also of vegetable origin, coal sometimes occurring changed to graphite when it has been subjected to high heat under pressure. Carbonaceous matters, of vegetable or animal origin, give the black color to black limestones and most shales, as is proved by the fact that when such rocks are burnt they become white, owing to the combustion of the carbonaceous part. Diamonds have probably been formed from the carbonaceous materials of a shale, by long subjection to heat and moisture, under peculiar conditions yet unexplained.

E. Aquatic species the largest rock-makers — The kinds of life which have contributed most material to the earth's rock-formations, and which are most common as fossils, are the *aquatic*, and particularly the *marine*. This is so because (1) the accumulation of material making beds of rock has been done mostly by the sea; because (2) the species which have the most stony matter in the structures, viz. corals, crinoids and shells are, with small exceptions, under the last division, aquatic, and nearly all are marine; because (3) the animal remains which are in the water readily become buried by new depositions of clay or sand through the currents or waves, and thus have a protection from destruction not afforded to any extent to species of the land; because (4) the water and this kind of burial also serve often as a preventive of complete decay. Coal has been made only where the plants grew in or near marshes or shallow lakes, or were drifted into bays or lakes; for the leaves that fall in the dry woods undergo complete decomposition, and pass away in

gaseous combinations. The bones of animals dropped over the land disappear by becoming the food of other animals as well as by decay; while those living about the shores of lakes have often become buried in lacustrine deposits of clay or finer earth, and thus have had their bones preserved. Mastodons have been mired in marshes and their skeletons preserved whole, while the thousands that died over the dry land left no relics.

F. Fossilization. — Shells, bones, corals, etc., after fossilization, have rarely their original composition. They have in almost all cases lost at least the animal matter they contained; frequently they are changed to quartz, sometimes to pyrite, oxide of iron, or dolomite, and occasionally to an ore of copper, or to a silicate of some kind. Wood is often changed to quartz or to limestone.

2. GEOGRAPHICAL DISTRIBUTION OF MARINE LIFE.

The distribution of species is an important subject to the geologist, but especially that of marine species, since the stratified rocks and their fossils are very largely of marine origin.

1. General Distribution in the Ocean. — Recent investigations have shown that living species not only inhabit the border regions of the oceans, but also extend widely and abundantly over a large part of the ocean's depths. Fishes, Crabs and other Crustaceans, Sea-worms, Echini, Star-fishes, Crinoids, Corals, are abundant to depths of 10,000 to 13,000 feet, and some of them to 18,000 feet. Crustaceans of large size, allied to shrimps, many of them with good eyes, have been found at all depths to 2,900 fathoms; and large crabs, with perfect eyes, at 1,700 fathoms. Some species have a very wide range in depth; one Coral (a disk-shaped kind, *Bathyaetia symmetrica*) occurs (states Moseley) at depths from 30 to 2,900 fathoms.

2. Character of the Sea-bottom. — The material of the ocean's

bottom is generally a fine grayish mud or ooze. But over vast regions above 13,000 feet in depth occurs the *Globigerina* ooze, and at these and greater depths other areas of Diatom ooze, and smaller of Radiolarian ooze.

The character of the bottom shows that sediments from the rivers of the continents are not carried far out to sea. Stones of a pound weight, and larger, occur 100 miles southeast of Long Island; but these are supposed by Verrill to have been carried out by shore ice. Clay with some fine quartz sand and particles of mica make up the gray ooze; and the winds may be a principal source of the sand and mica. Pumice and fine materials of volcanic origin are also widely distributed, indicating that the driftings by the winds from volcanic islands have been to great distances and over very large areas. The ooze has often a reddish color, which is attributed to the oxidation of the iron of the pyroxene or hornblende in volcanic cinders; and grains and nodules of oxide of manganese, probably from the same source, are very common over the ocean's bottom.

The bottom is the receiving place of all the dead remains of the ocean's life, both plant and animal, exclusive of the very large part that does not have a chance to reach the bottom, because of the eaters. In the Challenger expedition, the dredge, in one region, brought up a hundred or more shark's teeth, and between 30 and 40 ear-bones of Cetaceans or animals of the whale tribe. Among the shark's teeth, one was four inches wide at base, and apparently an Eocene tooth; and its being buried not more than a foot, although lying there since the early Tertiary, is regarded as evidence of the very small amount of detritus that falls over the bottom.

3. Causes limiting Distribution. — The two prominent physical causes limiting distribution are the amount of (1) *heat*, and (2) *light*.

a. Temperature. — The temperature of the waters varies (1) with the zones, from 90° F. in the tropics to 32° F., and even 28° F., in the polar seas; (2) with the distribution of marine

currents, the *warm* currents from the equatorial regions, and the *cold* from high latitudes; (3) with the depth, the temperature diminishing downward to 35° F. as a general thing, but in some places to 28° in the polar regions and polar currents. In depth, there is in the tropics a temperature of 45°, and often of 40°, within 300 fathoms of the surface, and almost everywhere of 40° and less, below 1,000 fathoms; so that from 1,000 fathoms to the greatest depths, the variation is only from 40° to 32° F., or in extreme cases to 28° F.

The influence of marine currents on the temperature is great. The *Gulf stream*, a deep Atlantic current, carries heat from the tropical to the polar seas. The portion of the broad current which passes through the Florida Straits is as deep as the Straits, 400 fathoms, and 83° to 44° F. in temperature, and has a maximum velocity of 5 miles an hour. It washes the deep-water border of the Atlantic basin at depths between 60 and 300 fathoms off Charleston, and between 60 and 150 fathoms (Verrill) southeast of New England; crosses the ocean northeastward to British seas, has a temperature of 45° off the Farøe Islands at a depth of 600 to 800 fathoms; and thence continues on pole-ward. From the polar regions the waters, chilled down to 39°–28° F., flow back, as the “Labrador current” along the east coast of America, and also southward beneath the warmer current over the ocean’s depths to the equator and beyond. Comparatively little goes out through Behrings Straits, because the depth is only 150 feet.

In the Pacific, there is a warm or tropical current on the west side, answering to the Gulf Stream of the Atlantic. Again, on the east side of the South Pacific, a reverse flow exists: a *cold-water current* from the southwest strikes the submarine slopes of southern South America, and carries cold to the equator, and thus narrows the region of tropical waters.

b. *Limiting range of Temperature for Species.* — The range of temperature favorable to any marine species is small — generally not over 20° F., and often less than 15° F. Within

the favorable temperature the species thrive; approaching the limit, the size usually diminishes; and beyond it, growth and egg-development cease. A current too cold for species within its reach is destructive, even more so than one of too much warmth. The enlarging of the polar current by an increase of high-latitude cold, as in a glacial era, might destroy the sea-border life of the oceans nearly to the equator.

c. *Light*. — Light is the chief limiting cause as to *depth* (Fuchs). If it were temperature, multitudes of species might grow hundreds of feet below their present level. Light has been found by experiment to penetrate downward in the ocean 43 to 50 fathoms; and what passes this limit is very feeble in amount. The species of depths less than 40 fathoms differ to a large extent from the deep-sea species, or those below this limit; they are (as stated by Fuchs) the *species of the light*, the latter the *species of the darkness*. The two ranges of species, the ocean-border (or species of the light) and the deep-sea species (or those of the darkness) are mingled somewhat between depths of 30 and 90 fathoms, and some shore species extend down to a much greater depth.

The eyes of animals of the deep or dark sea-depths are often blind, or else unusually large. The blindness is evidence of darkness, and the large eyes, of adaptation to the very feeble light of the regions. But this feeble light may be, as Dr. Carpenter, Wyville Thomson and others have supposed, that of phosphorescence; for many Crustaceans, Alcyonia, Starfishes, and other kinds are brightly phosphorescent.¹

4. **The Border Region, or that of the Animals of the Light.** Over the ocean's border region not only is the diversity of temperature between the equator and the poles felt in full

¹ The following are enumerated as the most characteristic types of the dark sea-depths. Of Corals, Oculinidæ, Cryptohelia and various solitary species; the Vitreous Sponges; Crinoids (Pentacrinus, Rhizocrinus, Hyocrinus, Bathyrinus); of Echinoids, Echinothuridæ, Pourtalesidæ, Ananchytidæ; of Asterioids, Brisinga; Holothuriæ of sub-order Elasmopodia; and Fishes, ribbon-like in form, of the families Lepidopidæ, Trachypteridæ, Macruridæ and Ophidiidæ.

force, but also that produced by the encroaching warm and cold currents. Off Eastern North America down to Cape Hatteras, the cold Labrador current cools the waters over the border region between the Gulf Stream, in 65 fathoms, and the shore line; while south of this cape the Gulf Stream has possession.

The other causes limiting distribution in the border regions of the ocean are: (1) the *condition of the water*, whether pure, or on the other hand, impure from sediments and fresh waters received from the land; (2) the *character of the bottom*, whether of mud, sand, or rock, and whether firm, or easily stirred and made impure by waves or currents.

Reef-forming Corals grow only in the sea-border regions of tropical seas, and at shallow depths. They extend from the equator to about latitude 28° , where the sea-temperature of the coldest month is not below 68° F. Owing to the warm Gulf Stream, they occur in the Atlantic in 34° north latitude, the Bermudas being of coral formation; and owing to the cold waters off western South America, they are excluded from that coast south of Guayaquil. In depth the limit is 18 to 20 fathoms. A vast variety of tropical species live and find shelter among coral reefs.

Sea-weeds, like other plants, are species of the light; they grow mostly within 10 fathoms of the surface, and rarely beyond 30.

In the *sea-depths*, or the *region of darkness*, the range of temperature is for the most part small — 55° to 30° . Only two well-marked divisions exist: that of the cold depths, the temperature below 45° F.; and that within the range of the tropical currents (as the Gulf Stream in the North Atlantic), the temperature mostly 45° to 55° F.

The border of the oceanic basin where swept by the Gulf Stream (page 72), both on its west side and in the British seas, is crowded with life, — species of Crustaceans, Echinoderms, Polyps, Mollusks, Worms, Fishes; and some kinds are larger than any of the same groups found in shallower

waters. Wyville Thomson mentions his bringing up 20,000 of one species of sea-urchin at one haul; and Verrill and Agassiz state parallel facts from the American seas.

The life from the cold and warmer regions differs to a great extent in species; and yet the groups represented in the two are largely the same. The colder depths are much less profuse in life, fail of some prominent groups, and contain many of very peculiar characters.

The cold and warm currents are in places in abrupt contact. The pushing of the former, along the eastern ocean-border of North America, over the narrow warmer area by westerly winds was probably the cause of the destruction of Fishes, Crustaceans, etc., of the latter that took place during the winter of 1881-82 (A. E. Verrill).

The following are further illustrations of the work of life.

3. PEAT-FORMATIONS.

Peat is an accumulation of half-decomposed vegetable matter formed in wet or swampy places. In temperate climates it is due mainly to the growth of mosses of the genus *Sphagnum*. These mosses form a loose, spongy turf, and, as they have the property of dying at the extremities of the roots while increasing above, they may gradually form a bed of great thickness. The roots and leaves of other plants, or their branches and stumps, and any other vegetation present, may contribute to the accumulating bed. The small Crustaceans, Worms, and various other kinds of species living in the waters, including often fresh-water Sponges, add to the material; the siliceous spicules of the sponges may generally be found in the ashes of the peat. The carcasses and excrements of large animals at times become included. Dust may also be blown over the marsh by the winds.

In wet parts of Alpine regions there are various flowering plants which grow in the form of a close turf, and give rise to beds of peat, like the moss. In Fuegia, although not south

of the parallel of 56° , there are large marshes of such Alpine plants, the mean temperature being about 40° F.

The dead and wet vegetable mass slowly undergoes a change, becoming an imperfect coal, of a brownish-black color, loose in texture, and often friable, although commonly penetrated with rootlets. In the change the woody fibre loses a part of its gases; but, unlike coal, it still contains usually 25 to 33 per cent of oxygen. Occasionally it is nearly a true coal.

Peat-beds cover large surfaces of some countries, and occasionally have a thickness of forty feet. One tenth of Ireland is covered by them; and one of the "mosses" of the Shannon is stated to be fifty miles long and two or three broad. A marsh near the mouth of the Loire is described by Blavier as more than fifty leagues in circumference. Over many parts of New England and other portions of North America there are extensive beds. The amount in Massachusetts alone has been estimated to exceed 120,000,000 of cords. Many of the marshes were originally ponds or shallow lakes, and gradually became swamps as the water, from some cause, diminished in depth.

Peat is often underlaid by a bed of whitish shell marl, consisting of fresh-water shells — mostly species of *Limnæa*, *Physa*, and *Planorbis* — which were living in the lake. The beds of white chalky material consisting of the siliceous shells of *Diatoms*, referred to on page 67, are often found beneath peat.

Peat is used for fuel, and also as a fertilizer. *Muck* is another name of peat, and is used especially when the material is employed as a manure; but it includes also impure varieties not fit for burning, being applied to any black swamp-earth consisting largely of decomposed vegetable matter.

Peat-beds sometimes contain standing trees and entire skeletons of animals that had sunk in the swamp. The peat-waters have often an antiseptic power, and flesh is sometimes changed by the burial into adipocere.

4. CORAL-REEFS.

In tropical regions corals grow in vast plantations about most oceanic islands and along the shores of continents. In the shallow waters the patches or groves of coral are usually distributed among larger areas of coral sand, like small groves of trees or shrubbery in some sandy plains.

The corals have much resemblance to vegetation in their forms and their modes of growth; and the animals are so like flowers in shape and bright colors that they are often called *flower-animals* (page 184). Along with the corals there are also great numbers of Shells, besides Crabs, Echini, and other kinds of marine life.

The coral plantations are swept by the waves, and with great force when the seas are driven by storms. The corals are thus frequently broken, and the fragments washed about until they are either worn to sand by the friction of piece upon piece, or become buried in the holes among the growing corals, or are washed up on the beach. Corals are not injured by mere breaking, any more than is vegetation by the clipping of a branch; and those that are not torn up from the very base and reduced to fragments continue to grow.

The fragments and sand made by the waves, and by the same means strewed over the bottom, along with the shells also of mollusks, commence the formation of a bed of coral-rock, — literally a bed of limestone, for the coral and shells have the composition of limestone, — and consolidation goes on simultaneously. As the corals continue growing over this bed, fragments and sand are constantly forming, and the bed of limestone thus increases in thickness. In this manner it goes on increasing until it reaches the level of low tide; beyond this it rises but little, because corals cannot grow where they are liable to be left for a day wholly out of water; and the waves have too great force at this level to allow of their holding their places, if they were able to stand the hot and drying sun. A bed of calcareous rock is thus produced which is a *coral reef*.

Since reef-corals grow to a depth of only 100 feet (page 74), the thickness of the reef cannot much exceed 100 feet if the sea-bottom remains at a constant level, except where there are oceanic currents to transport to greater depths the sand that is made. But should the reef-region be slowly sinking, at a rate not faster than the corals can grow and make the reef rise, then almost any thickness may be attained. From observations about the coral regions of the Pacific, it is supposed that some of the reefs have acquired a thickness of two or three thousand feet or more, during such a slow subsidence.

Fig. 89.



View of a high island, bordered by coral-reefs.

The coral formations of the Pacific are sometimes broad reefs around hilly or mountainous islands, as shown in the annexed sketch. To the left, in the sketch, there is an inner reef and an outer reef, separated by a channel of water, the inner of which (*f*) is called a *fringing* reef, and the outer (*b*)

Fig. 90.



Coral island, or atoll.

a *barrier* reef. They are united in one beneath the water. At intervals there are usually openings through the barrier reef, as at *h, h*, which are entrances to harbors. The channels are sometimes deep enough for ships to pass from harbor to harbor.

Many coral-reefs stand alone in the ocean, far from any other lands (Fig. 90). These are called *coral islands* or *atolls*.

They usually consist of a narrow reef encircling a salt-water lake. The lake is but a patch of ocean enclosed by the reef with its groves of palms and other tropical plants. When there are deep openings through the reef, ships may enter the lake, or *lagoon* as it is usually called, and find excellent anchorage. The annexed figure (Fig. 91) is a map of one of the atolls of the Gilbert (or Kingsmill) Islands in the Pacific. The reef on one side — the windward — is wooded throughout; but on the other it has only a few wooded islets, the rest being bare and partly washed by the tides. At *e* there is an opening to the lagoon.

Fig. 91.



Apla, of the Gilbert group.

The Paumotu Archipelago, east-northeast of the Society Islands, contains between 70 and 80 coral islands; the Carolines, with the Radack, Ralick, and Gilbert groups on the east and southeast, as many more; and others are scattered over the intervening ocean. Most of the high islands between the parallels of 28° north and south of the equator (where the seas are sufficiently warm, page 74) have a fringe of coral-reefs.

The limestone beds made from corals and shells are not a result of growth alone, as in the case of the deposits formed from microscopic organisms, but of growth *in connection with the breaking and wearing action of the ocean's waves and currents*. Corals and shells, unaided, could make only an open mass full of large holes, and not a solid rock. There must be sand or fine fragments at hand, such as the waves can and do constantly make in such regions, in order to fill up the spaces or interstices between the corals or shells. If there is clayey or ordinary siliceous sand at hand, this will suffice, but it will not make a *pure* limestone; in order to have the rock a true limestone, the shells and corals must be the

source of the sand or fine fragments, for these alone yield the needed calcareous material and cement. The limestone made in this way by the help of the waves may be, and often is, as fine-grained as a piece of flint or any ordinary limestone, it having been formed, in such a case, of the finest coral sand or mud. In other cases, it contains some imbedded fragments in the solid bed; in others, it is a coral conglomerate; and, over still other large sheltered areas, it is a mass of standing corals with the interstices filled in solid with the sand and fragments.

Along the shores, above low tide, the sands are agglutinated into a beach sand-rock, and the beds have the slope of the beach, or 5° to 15° . The waters contain lime (calcium bicarbonate) in solution; and as the sands, wet at high tide, dry again when the tide is out, the calcareous cement is deposited between the grains, and so consolidation goes forward. The cement coats the grains with carbonate of lime; and either in this way, or by its own concretionary tendencies, the rock sometimes becomes an oölyte (page 37).

The process of limestone-making now going on through the agency of coral animals illustrates equally the method from shells and crinoids. The extent of some of the modern reefs matches nearly that of the largest Paleozoic reefs. On the north of the Feejee Islands the reef-grounds are 5 to 15 miles in width. In New Caledonia they extend 150 miles north of the island and 50 miles south, making a total length of 400 miles. Along Northeastern Australia they stretch on, although with many interruptions, for 1,000 miles.

B. Protective and Destructive Effects.

a. Protective Effects. — Slopes are protected from erosion through a covering of turf; sand-hills, from the winds, through tufts of grass and other vegetation; shores, from the surf in many places, by a growth of long sea-weeds; and the

outer margins of coral-reefs, by a growth over the exposed surface of calcareous vegetation, called Nullipores.

Further, forests keep a vast amount of moisture in the wet ground beneath them, which is *gradually* supplied to the streams as from a reservoir, making them serviceable for mills and other purposes through the year; whereas, if cut away, the rains fill suddenly the river-channels, producing disastrous floods, and the long droughts which intervene are seasons of dwindled and useless waters. And, besides, the floods carry away the soil from the steep hill-sides, and may reduce a productive region to one of rocky ledges. These evils are already a reality in portions of North America, and are on the increase.

b. Destructive Effects. — Rocks, where jointed or fissured or laminated, are torn asunder and often upturned by the growth of seed in a crevice, and the subsequent enlargement of the root and stem, — trunks sometimes growing to a diameter of several feet and as gradually opening the crevice, and thus displacing great masses. The same agency opens crevices to moisture, and so promotes decomposition; and it prepares for the action of freezing in winter (page 115).

Boring animals cause destruction in various ways. The mole, mouse, and some other animals tunnel embankments, and open a channel for the exit of the confined waters, which rapidly enlarges; and sometimes a vast amount of erosion is occasioned by the waters thus discharged. The levees of the Mississippi are thus tunnelled by crawfish, occasioning great floods and devastations. Boring shells, as the *Saxicavæ* weaken the parts of rocks exposed to the surf.

The decay of vegetable and animal matters in the soil produces organic acids as well as carbonic acid, which erode rocks and promote their decomposition.

The preying of one kind of life on another has had great effect toward determining the prevalence, or the dwindling and destruction, of species, besides giving occasion for adaptations to new conditions.

II. CHEMICAL ACTION OF THE AIR AND WATERS.

Geological work of a *destructive* kind is carried forward in a quiet way through the chemical action of the constituents of the earth's atmosphere and waters, preparing thus for the rougher mechanical work of these agents; and the same processes have their *formative* effects.

1. **Oxygen** is a constituent both of air and water, it being mixed with nitrogen to form air, and combined with hydrogen to form water (H_2O); and many substances in minerals or rocks have an intense affinity for oxygen.

a. Iron rusts because of its tendency to combine with oxygen; and *iron in the protoxide state* (FeO) will take more oxygen, and so pass to the *sesquioxide state* ($Fe_2O_3 = FeO_1\frac{1}{2}$). Consequently, a mineral containing iron in the former state, like pyroxene, hornblende, black mica, and other species, often goes to destruction through this affinity; and hence rocks containing these minerals (like trap) usually suffer easy decomposition; for disturbing one constituent is, like taking a stone from an arch, destruction to the whole. The other ingredients of the iron-bearing mineral are set free to make earth, and commonly the associated minerals participate in the decay and add to the earth. The iron in the sesquioxide state makes a *red earth*, and is the species hematite. But it generally combines with water, and becomes a brownish-yellow earth which is *yellow ochre*, or the mineral called limonite; it may be pure limonite, but it is usually mixed with the other materials of the rock, or makes ochreous stains over the surfaces of fissures or joints.

In this process of oxidation, moisture as well as air must be present; the oxygen taken up is usually derived from the moisture.

b. Again, *iron when combined with sulphur*, constituting a sulphide of iron, like *pyrite* (FeS_2), or *pyrrhotite* ($Fe.S_3$),

oxidizes readily (unless in the firmest crystals), and passes to the same state of yellow-ochre or limonite (4FeS_2 becoming $2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O} = 2\text{Fe}_23\text{H}_2\text{O}_3$). The sulphur also oxidizes and becomes *sulphuric acid*, which is a destructive agent, owing to its tendency to take into combination many of the ingredients of minerals, as lime, magnesia, soda, potash, alumina, and also iron; and it hence aids much in the work of destruction. This acid may combine with the iron, and so make *green vitriol*; but as its affinity for the substances above enumerated is stronger than for iron, the iron is usually left in the ochreous state.

Now sulphide of iron, in the form of pyrite or pyrrhotite, is disseminated more or less abundantly through nearly all the rocks of the globe, occurring in most granite, syenite, gneiss, mica and other schists, and slates, sandstones, shales, much trap, and many limestones; and hence, rocks in all lands are undergoing destruction through this agency. Many a fair-looking building-stone is rendered worthless by it. It is the most universal of rock-destroyers. When the minute grains of pyrite in a granite or sandstone oxidize, the other mineral particles of the rock are set loose and become discolored with the ochre that is made; and the sulphuric acid, at the same time formed, eats into some of those grains to cause their decomposition. Thus the granite either (*a*) disintegrates into a loose granitic sand, or (*b*) it becomes decomposed to earth or clay. Blocks of trap have a thin decomposed crust which is incessantly receiving additions inside while losing outside.

The decomposition of sulphide of iron in shales or clays often forms *alum*, and makes *alum-clays*, because of the combination of the sulphuric acid with the alumina of the rock, and usually with some other base in the protoxide state, as potash, soda, magnesia etc.

2. Carbonic Acid (CO_2) is present in the atmosphere, about 3 parts in 10,000 by volume consisting of this gas. It is present in all rain-water, the rain-water deriving it from the

atmosphere. It is present in the soil, being produced where the material of plants and animals is undergoing slow decomposition; and thence it is given to the waters percolating through soils. By all the methods mentioned, and also through animal respiration, the sea derives carbonic acid. Moreover, in the earlier ages of the globe, the amount of carbonic acid in the atmosphere and waters far exceeded the present.

Carbonic acid tends strongly to form combinations with magnesia, lime, potash, soda, and with iron in the protoxide state. Hence a feldspar, since it yields potash, soda, or lime, is liable to have its alkali carried off by percolating waters; and with such a loss, the mineral changes to a hydrous clayey mineral called *kaolin*, — the material used in making porcelain. Common feldspar yields on analysis 17 per cent of potash, 18.5 of alumina, and 64.5 of silica; and kaolin, no potash, 14 of water, 40 of alumina, and 46 of silica. Granite and other rocks are often eaten into by this process, so as to be fragile to the depth of a foot or more, and sometimes to a depth of 50 or 100 feet.

Fig. 92.

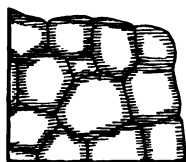
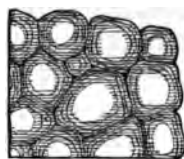


Fig. 93.



The depth of decomposition, by either method, is measured by the depth to which moisture is absorbed; so that the architectural value of a stone is inversely as its absorbent quality. All cracks or joints by which water enters may have a discolored border of like depth (Fig. 92); and the process goes on by this means, in some granite, trap, and other rocks, until the mass becomes reduced to what looks like a pile of large spheroidal concretions (Fig. 93); and ends finally in making earth, or loose sand, of the whole.

When the iron-carbonate (called *siderite*) is left exposed to the air and moisture, the iron oxidizes, and changes to limonite. So any limestone that contains iron, replacing part of the calcium or magnesium, will readily become brown and crumble.

The decomposition of iron-bearing minerals is promoted by the action of carbonic acid, or of an organic acid derived from the soil waters. These acids extract the iron protoxide and make with it a soluble salt of iron, and thus, by the aid of streamlets, may carry the iron away. In order that carbonic acid should thus take up iron, and make the soluble *bicarbonate*, it must be under pressure, and the carriers *now* are the organic acids; but in ancient time, when the atmosphere was much denser than at present, carbonic acid may have done this work. The salt of iron becomes oxidized in the low places or marshes to which it may be carried, because the waters thus get more of the salt that they can dissolve, and forms there a yellow or brown or brownish-black deposit of limonite or a related ore.

The organic material of the soils, owing to its using oxygen when decomposing, will take it from any Fe_2O_3 present, and may thus change it to FeO , and this FeO then combine with the organic acid or carbonic acid at hand. Many red beds of rocks have lost the red color in spots or seams or along cracks, by this method of deoxidation.

Waters containing carbonic acid readily erode limestone. The limestone is taken up and a *calcium bicarbonate* is formed, which is soluble. On evaporation, the bicarbonate loses its excess of carbonic acid, and the limestone taken up is again deposited. Thus limestone strata are eroded, and caverns made; and through the depositions, the caverns are hung with stalactites and floored with stalagmite. (See pages 102, 104).

Deposits formed; Rocks consolidated. — (1) By the processes above-mentioned, from iron-bearing limestone or iron carbonate, great beds of *limonite*, of the purest quality, have been made (some, over 100 feet deep); and they often lie *in place*,

that is, occupy the depressions produced by the decomposition. Those of Richmond and West Stockbridge in Massachusetts, of Salisbury in Connecticut, of Millerton and other places in eastern New York, and of many localities south of New York in Pennsylvania and Virginia, are of this kind. Again, the iron-salts carried to marshes — the pockets of a region — have often made large beds of the related *bog ore*; but such ore is likely to contain sulphur (from decomposed pyrite) and phosphorus (from the decomposing organic material present) and hence the iron afforded is of inferior quality.

(2) From the feldspar decompositions have come large beds of *kaolin*; and some of the best and largest have been made from quartzites containing disseminated feldspar, as in the southern margin of New Marlborough, Mass.

(3) Carbonated waters, besides forming stalactites, have made large beds of limestone, like the travertine of Tivoli, near Rome, and the so-called alabaster of Mexico.

Carbonated waters, besides serving in the consolidation of limestones (page 80), often also consolidate sand-beds, gravel-beds, and clay-beds, when *grains of limestone* are even sparingly present; and very commonly the solidification takes place around centres (some grain, or it may be fossil, serving as the nucleus) and so makes *concretions* (page 47) in the bed, complete consolidation often following later. Again, consolidation takes place to some extent through depositions of limonite in pebble-beds and sand-beds. But the more common method of solidifying such fragmental deposits is through *siliceous* waters (page 147).

III. THE ATMOSPHERE.

The following are some of the mechanical effects connected with the movements of the atmosphere.

1. **Transportation of sand, dust, etc.** — The streets of most cities, as well as the roads of the country, in a dry summer

day, afford examples of the drift of dust by the winds. The dust is borne most abundantly in the direction of the prevalent winds, and may in the course of time make deep beds. The dust that finds its way through the windows into a neglected room indicates what may be done in the progress of centuries where circumstances are more favorable.

The moving sands of a desert or sea-coast afford the more important examples of this kind of action.

On sea-shores, where there is a sea-beach, the loose sands composing it are driven inland by the winds into parallel ridges higher than the beach, forming *drift-sand hills*. They are grouped somewhat irregularly, owing to the course of the wind among them, and also to little inequalities of compactness, or to protection from vegetation. They form especially (1) where the sand is almost purely siliceous, and therefore not at all adhesive even when wet, and not good for giving root to grasses; and (2) on windward coasts. They are common on the windward side, and especially the projecting points, even those of a coral island, but never occur on the leeward side, unless this side is the windward during some portion of the year. The stratification in such drift-hills is of the kind represented in Fig. 22 *f*, page 45, and shows that the growing hill was often cut partly down or through by storms, and was again and again completed after such disasters. On the southern shore of Long Island series of such sand-hills, 10 to 30 feet high, extend along for 100 miles. They are partially anchored by straggling tufts of grass. The coast of New Jersey down to the Chesapeake is similarly fronted by sand-hills. They occur also on the east coast of Lake Michigan. In Norfolk, England, between Hunstanton and Weybourne, the sand-hills are 50 to 60 feet high.

Dust is carried by storm winds, sometimes hundreds of miles. A shower covered the Cape Verdes with dust from Africa, nearly 1,000 miles distant, and was 1,600 miles broad (Darwin). Volcanic dust was carried, in 1835, from Guatemala to Jamaica, 800 miles. Birds and insects are thus car

ried to sea. In one dust-shower, about Lyons in France, 720,000 pounds of dust fell, and, of this, 90,000 consisted of Diatoms and other organic relics (Ehrenberg).

2. Additions to land by means of drift-sands. — The drift-sand hills are a means of recovering lands from the sea. The appearance of a bank at the water's surface off an estuary at the mouth of a stream is followed by the formation of a beach, and then the raising of hills of sand by the winds, which enlarge till they sometimes close up the estuary, exclude the tides, and thus aid in the recovery of the land by the depositions of river-detritus. Lyell observes that at Yarmouth, England, thousands of acres of cultivated land have thus been gained from a former estuary. In all such results the action of the waves in first forming the beach is a very important part of the whole.

3. Destructive effects of drift-sands. — Dunes. — Dunes are regions of loose drift-sand. In Norfolk, England, between Hunstanton and Weybourne, the drift-sands have travelled inland with great destructive effects, burying farms and houses. They reach, however, but a few miles from the coast-line, and were it not that the sea-shore itself is being undermined by the waves, and is thus moving landward, the effects would soon reach their limit. East of Lake Michigan the sand-hills have a height of 100 to 200 feet; and even 215 feet at Grand Haven, where, according to A. Winchell, the forest has been buried so as to leave only the "withered tree-tops projecting a few feet above the waste of sands." In the desert latitudes, drift-sands are more extended in their effects.

4. Abrasion; Sand-scratches. — The sands carried by the winds, when passing over rocks, sometimes wear them smooth, or cover the surface with scratches and furrows, as observed by W. P. Blake on granite rocks at the Pass of San Bernardino in California. Ledges and bluffs have been deeply eroded and shaped or worn away by this agency. Similar effects have been observed by Winchell in the Grand Traverse

region, Michigan. Glass in the windows of houses on Cape Cod sometimes has holes worn through it by the same means. The hint from nature has led to the use of sand, driven by a blast with or without steam, for cutting and engraving glass, and even for cutting and carving granite and other hard rocks.

5. Winds as transporters of Moisture.—The atmosphere takes moisture from the ocean and land, proportionally to its temperature, and transports it. If the air increases in temperature as it passes over a continent, it keeps taking up moisture, and so dries up the land; if, on the contrary, it loses in temperature, its capacity for moisture is lessened, and it drops it, making rain and mists over the land. If the warm wind strikes the cold side or summit of a mountain, the moisture is largely dropped, so that little remains for the region on the opposite side of the mountain, which therefore experiences drought.

The trade winds are movements of the air within the tropics *westward*, against the *east* side of the continents; they are warm winds, well charged with moisture. Near and over the continents they bend away from the equator and thus pass to colder regions; hence they are moist winds, giving abundant rains. Consequently the eastern portions of continents are regions of much rain; and the farther back from the east coast the higher mountains are set the larger the surface benefited by the rains. The great Gulf of Mexico is of immense service to North America as a source of water-supply to the winds; and so also is the position of the high Rocky Mountains, so far away from the eastern coast.

The winds over the ocean, north of the parallel of 30° to 60° , are movements of air *eastward*, and therefore against the *west* side of the continents; they are not warm winds, and not abundant in moisture. Near and over the continents they bend equator-ward and pass generally over warmer regions; hence they are drying winds; and consequently the western portions of continents are regions of less rain than

the eastern; and on the western portions, between latitudes 25° and 35° exist the chief desert regions of the continental borders.

Thus the winds are largely the distributors of fertility, the locators of great forest regions and deserts, and the limiters of distribution for the living species of the land; and they have done their work in the same way essentially through all past time, and in general with like geographical effects over the same regions from one age to another. America has always been, as Guyot has styled it, the *forest continent*.

IV.—WATER.

The following subdivisions are here adopted:—

1. FRESH WATERS; or those of Rivers and Lakes.
2. The OCEAN; and, with it, the larger Lakes.
3. FROZEN WATERS, or Glaciers and Icebergs.

1. Fresh Waters.

A. Superficial Waters, or Rivers.

The working force or energy of moving waters depends on gravity, and is determined, in any case, by (1) the volume of water and (2) the amount of its fall. This energy may be used up (1) in overcoming the friction due directly to the motion,—in which erosion of the bed may be produced; (2) in transporting earth or stones,—the source of most fragmental deposits; and (3) in overcoming the friction arising from the abrasion of the particles of the transported material against the bed and among themselves,—another source of erosion.

1. Erosion.

1. **Sources of streams; Drainage-areas.**—The waters of rivers descend in the form of rain and snow from the clouds, and are derived by evaporation both from the surface of the

land, with its lakes, rivers, and foliage, and from the ocean, but mostly from the latter. The waters rise into the upper regions of the atmosphere, and, becoming condensed into drops or snow-flakes, fall over the hills and plains. They gather first into rills; these, as they descend, unite into rivulets; these, again, if the region is elevated or mountainous, into torrents; torrents, flowing down the different mountain valleys, combine with other torrents to form rivers; and rivers from one mountain-chain sometimes join the rivers from another and make a common stream of great magnitude, and great *drainage-area* like the Mississippi or the Amazon.

The Mississippi has its tributaries among all the eastern heights of the great Rocky Mountain chain, throughout a distance of 1,000 miles, or between the parallels of 35° N. and 50° N.; and still another set of tributaries gather waters from the Appalachian chain, between Western New York and Alabama. Rills, rivulets, torrents, and rivers combine over an area of millions of square miles to make the great central trunk of the North American continent.

The amount of water poured each year into the ocean by the Mississippi averages 19½ trillions (19,500,000,000,000) of cubic feet, varying from 11 trillions in dry years to 27 trillions in wet years. This amount is about 25 per cent of that furnished by the rains, the rest being lost mostly by direct evaporation, but also in part by absorption into the soil and strata and by contributing to the growth of vegetation.

Snowy mountains deal out water gradually under the control of the sun and winds, day and night and summer and winter making alternations in the supply to the streams. Forest regions also are like reservoirs in holding on long, and supplying gradually, the waters beneath them.

2. Erosion. Valley-making. — *Erosion* or wear (termed also *denudation*) and *transportation* are consequences of motion. The rain-drop makes an impression where it falls (Fig. 27, page 47); the rill and rivulet carry off light sand and deepen their beds, as may be seen on any sand-bank or by many a

roadside; torrents work with greater power, tearing up rocks and trees as they plunge along, and, in the course of time, make deep gorges or valleys in the mountain-slopes; and rivers, especially in periods of flood, hurry on with vast power, making wider valleys over the breadth of a continent. The slopes of a lofty mountain, exposed through ages to the action described, finally become reduced to a series of valleys and ridges, and the summit often to towering peaks and crested heights,—all these effects originating in the fall of rain-drops or snow-flakes.

Flood-time is the period of active work. Before, streams are often almost still from (1) want of slope, or (2) the friction between the large bed and the little water; but at flood-height the waters at their high level have (1) augmented slope, and, (2) relatively to the amount of water, largely diminished friction; and hence comes the greater velocity. The Connecticut, to Hartford, 36 miles (in an air line), is a tidal stream, zero in working force at low water and tide; but in its highest flood (30 feet at Hartford) it has a mean pitch to the Sound of 10 inches a mile, and flows off with great rapidity. On mountain streams the transition is often from almost or quite zero to a succession of cataracts of vast working force.

Nearly all the deep valleys of the world owe their excavation to running water. Their positions have sometimes been determined by fissures in the earth's strata, or by the courses of the lowlands left between mountain chains; but, generally, rivers have worked out their own channels from their beginnings onward to their present depth and extent.

With steep slope, as in many mountain regions, the stream excavates rapidly, and carries off what it gathers instead of depositing it, the powers of erosion and transportation being great; consequently the valley it makes is more or less V-shaped. But, where the slope is gentle and the velocity small, the erosion at bottom becomes feeble or null; in times of flood the waters spread over the banks and tend to widen the valley as they rush along by its sides; at the same

time, with declining floods and slackening velocity, depositions take place of the transported material, owing to friction, making an *alluvial* flat, or flood-plain, where the retardation is greatest on one or both sides, and so the valley becomes U-shaped. Rivers, hence, have ordinarily a narrow *channel* for the dry season, and a *wide flood-plain* which is its bottom in time of flood.

3. Methods of Erosion. — Erosion is carried forward mainly by the following methods :—

a. By the friction or strokes of the flowing waters. — In a rapid stream, especially when increased in depth and speed by floods, the waters often throw themselves in large volumes into cavities or recesses among the rocks, and thus tear away obstacles, overcome cohesion in the softer deposits within reach, wrench out masses of rock where the beds are laminated or jointed (and nearly all rocks are jointed), and by this means, and by undermining, make rapid destruction of exposed ledges and piles of strata, and so carry on the excavation of the channel. Where the pitch is large, the waters accumulate working-force by the descent, augmenting the effects. Over smoothly rounded or even surfaces, the effect is very feeble.

b. By the abrading action of transported earth and stones. — The earth and stones carried along by a stream abrade the bottom and sides of the channel, and so carry forward the work of excavation. There is mutual abrasion of the earth and stones, resulting in increasing their fineness and their transportability. A stream seldom does so much transporting work as to lose all abrading power, and never when a large and rapid torrent.

c. Aid from decomposition and solution. — The decomposing and dissolving action of the water takes an important part in the work of denudation. Decomposition and disintegration (pp. 82–85) are going on over almost all exposed surfaces of rocks, thus making softened material for the abrading and transporting rills and rivers. Solution also has large effects, especially in limestone regions ; it helps greatly in the exca-

vation of valleys, and finds in the joints of the rocks a chance to begin the work (page 84).

The rounded stones, gravel, and earth of fields, and also the material of most geological formations, has been made out of pre-existing solid rocks, to a large degree by the wearing action of waters, — either those of streams over the land, or those of the ocean. But this action is, and ever has been, greatly aided by the processes of decomposition or disaggregation due to the elements. This last-mentioned cause is sufficient alone to turn angular blocks of most rocks into rounded masses.

The finer transported material is called *detritus* (from the Latin for *worn out*) and also *silt*. The larger rounded stones are termed *boulders*.

4. Cascades.—A cascade usually occurs on a rapid stream, where in the course of it there is a hard bed of rock overlying a soft one. The hard bed resists wear, while the soft one below yields easily: thus a plunge begins, which increases in force as it increases in extent. At Niagara Falls, 80 feet of shale under-lie 80 feet of hard limestone (Fig. 14, p. 40). Rills and rivulets made by a shower of rain along road-sides or sand-banks often illustrate also this feature of great mountain-streams.

5. Features produced where Strata are nearly Horizontal. Mountains of Circumdenudation.—When the rocks underlying a region are *nearly horizontal*, the valleys cut by the rivers have usually bold rocky sides. In many parts of the Rocky Mountains the streams have worked their way down through the rocks for hundreds, and in some places even thousands, of feet. Such a place is often called a *cañon*.

These *cañons* are of wonderful depth and magnitude on the Colorado River, over the west slope of the Rocky Mountains, between longitude 111° W. and 115° W. For 300 miles there is a nearly continuous *cañon*, 3,500 to 6,000 feet deep. The following sketch, from one of the excellent photographs of the region by the artist of Powell's Expedition, represents a portion of it, called the Marble *Cañon*. The rocks stand in

nearly vertical precipices either side of the stream, and the height above the water to the top of the bluff seen in the distance is 5,000 feet. The deep gorge is the result of erosion by the stream, which is still continuing its wearing action.

Fig. 94.



Cañon of the Colorado.

In large parts of the cañon are crowds of peaks and temple-shaped summits, some of them 5,000 feet high, all of which are the work of the waters since the era of the early Tertiary. Moreover, above the walls of the cañon, over the country to the northward, rise plateaus and mountains, in which the strata are piled up to an additional altitude of 5,000 to 7,000 feet, which are portions of great formations that once spread over the whole region. The mountain ridges and peaks of Colorado, Utah, and the adjoining territories.

12,000 to 14,000 feet in height, are other fragments of the same strata, and often show nearly horizontal beds to their tops.

When mountain forms have thus been made they are sometimes called *mountains of circumdenudation*. Given a great elevated plateau in a region of rains, and mountain-sculpturing will go on about it, and may continue until all is ridge and valley, not a square mile of the original plateau retaining its flat surface; and the resulting crested ridges may rise thousands of feet above the bottoms of the valleys, if the plateau is one of sufficient height. The Catskill Mountains, New York, are an example of a mountain of circumdenudation; and most of the mountains of Utah and Colorado are other examples. The wear is much the most rapid when there is little vegetation over the surface.

The following figures, by Lesley, illustrate some of the results of the sculpturing by water, in both horizontal and upturned or flexed strata. In the production of such elevations, the ocean has sometimes taken part during the submergence of a continent; but the final results are, in almost all cases, due to the chisellings of fresh waters. The figures here given are small, but the elevations they represent, as illustrated in the Appalachians, Juras, and many other mountain regions, are often thousands of feet in height.

When the beds are *horizontal*, or nearly so, but of *unequal hardness*, the softer strata are easily worn away, and by this means the harder strata become undermined. Table-lands

Fig. 95.



Fig. 96.



are often thus formed, having a top of the harder rock, and the declivities usually banded with projecting shelves and intervening slopes. Figs. 95, 96 represent the common character of such hills. Such flat-topped elevations in the

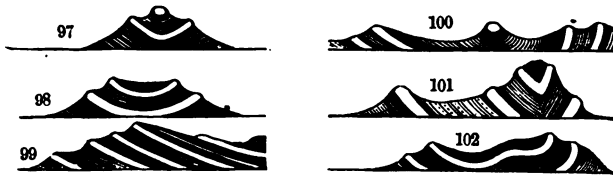
Colorado region have been called *mesas*, from the Spanish for *table*.

When the beds are inclined between 5° and 30° , and are alike in hardness, there is a tendency to make hills with a long back slope and bold front; but with a much larger dip, the rocks, if hard, often outcrop in naked ledges.

When the dipping strata are of unequal hardness, and lie in folds, there is a wide diversity in the results on the features of the landscape.

Figs. 97, 98 represent the effects from the erosion of a *synclinal* region consisting of alternations of hard and soft

Figs. 97-102.



strata. The protection of the softer beds by the harder is well shown. This is still further exhibited in Figs. 99-102.

Anticlinal strata give rise to another series of forms, in part the reverse of the preceding, and equally varied. Figs. 103-106 represent some of the simpler cases. When the back of an anticlinal mountain is divided (as in Figs. 103-105), the mountain loses the anticlinal feature, and the

Figs. 103-106.



parts are simply *monoclinical* ridges. In Fig. 106 the anticlinal character is distinct in the central portion, while lost in the parts on either side. In Fig. 106, to the right, a common effect is shown of the protection afforded to softer layers by

even a vertical layer of hard rock: the vertical layer forms the axis of a low ridge.

2. Transportation by Rivers, and distribution of transported Material.

1. Fact of transportation. — It has been stated that the massive mountains have been eroded into ridges and valleys by running water. The material worn out has been transported *somewhere* by the same waters.

Part of the transported material in all such operations goes to form the great alluvial plains that occupy the river-valleys throughout their course. Part is carried on to the sea into which the river empties, where it meets the counteracting waves and currents and is distributed for the most part along the shores, filling estuaries or bays, or making deltas, and extending the bounds of the land.

Thus the mountains of a continent are ever on the move seaward, and contribute to the enlargement of the sea-shore plains. The continent is losing annually in mean height, but gaining in width, or extent of dry land.

2. Transporting power of water. — The transporting power of running water is very great when the flow is rapid. Large stones and masses of rocks are torn up and moved onward by the mountain-torrent. It has been calculated, after some trials, that a current of *four miles an hour* will carry stones $2\frac{1}{2}$ inches in diameter; of *two miles*, pebbles of 0.6 inch; of *two thirds* of a mile, fine sand, about .064 in diameter; of *one third* of a mile, fine earth or clay, the particles .016 in diameter; the *mean diameter of the largest transportable particles varying as the square of the velocity*, supposing them of like density.

Hence, as a stream loses in velocity it leaves behind the coarser material, and carries only the finer; if the rate becomes very slow, it drops the gravel or the sand, and bears on only the finest earth or clay. Consequently, where the

current is swift, the bottom (and the shore also, wherever the current strikes it) is stony or pebbly; and where the water is still, or nearly so, the bottom and shores are muddy.

3. Amount of material transported. — The amount of transported material varies with the size and current of the rivers and the kind of country they flow through. The Mississippi carries annually to the Gulf of Mexico, according to Humphreys and Abbot, on an average, 812,500,000,000 pounds of silt, — equal to a mass one square mile in area and 241 feet deep, — and its bottom waters push on enough more to make the 241 feet 268 feet. The process slowly lowers the drainage area of the river, and the mean amount of lowering indicated by the facts stated is one foot in 4,920 years. The total annual discharge of silt by the Ganges has been estimated at 6,368,000,000 cubic feet.

Besides the silt, rivers carry what the waters take into solution. The amount is generally between a third and a half of that mechanically transported; but sometimes nearly an equal weight. If one half, in the case of the Mississippi, the interval 4,920 years becomes 3,280. The salts held in solution are often about one half calcium carbonate, and the rest calcium sulphate, sodium chloride (common salt), and magnesian and potash salts, with traces of silica and other ingredients. The contributions of these salts from rivers to the ocean must be making a slow increase of its saltiness. In some cases the rivers carry the salts to inland seas or plains, which have no drainage toward the ocean, and which therefore are saline. Besides, arid plains become saline because of the capillary action which brings moisture from below to the surface, as evaporation goes on above depositing the contained saline ingredients, such as the sodium chloride, sodium carbonate, and magnesian salts of such places.

4. Alluvial or Fluvial formations. — The deposits made by the transported material which now constitute the alluvial plains of the river-valleys cover a large part of a continent, since rivers or smaller streams are almost everywhere at

work. They are made up of layers of pebbles or gravel, and of earth, silt, or clay, especially of these finer materials. Logs, leaves, shells, and bones occur in them: but these are rare; for whatever floats down stream is widely scattered by the waters, and to a great extent destroyed by wear and decay. The level of the alluvial plain is ordinarily that of the level of the higher floods, and hence the name of *flood-plain* often applied to it. The spreading waters, by here losing their velocity, owing to friction, built up the deposits. The river margin is often a little above flood-level.

5. Terraces. — River-valley or fluvial formations are often in terraces. The terraces are in general a consequence of floods far higher than ordinary floods (like those after the Glacial era, page 355), their plains being true flood-plains. But some terraces have been formed by the abrasion of higher terraces. Others, on bays, are alluvial flats left high, after a change of level; and sea-shore flats and beaches, and horizontal lines of wave-erosion on cliffs, have often been left high in the same movements.

6. Estuary and Delta formations. — The detritus-material discharged by the river at its mouth tends to fill up the bay into which it empties, and make wide flats on its borders, and thus contract it to the breadth merely of the river-current.

Where the tides are feeble and the river large, the deposits about the mouth of the stream gradually encroach on the ocean, and make great plains and marshy flats, which are intersected by the many mouths of the river and a network of cross-channels. Such a formation is called a *delta*. Fig. 107 represents the *delta* of the Mississippi, the white lines being the water-channels and the black the great alluvial plains. The delta properly commences below the mouth of Red River, where the Atchafalaya *bayou*, or side-channel of the river, begins. The whole area is about 12,300 square miles; about one third is a sea marsh, only two thirds lying above the level of the Gulf.

The deltas of the Nile, Ganges, and Amazon are similar in general features to the delta of the Mississippi.

The detritus poured into the ocean where the tides or currents are strong, and a considerable part of that where the

Fig. 107.



Delta of the Mississippi.

tides are feeble, goes to form sea-shore flats and sand-banks and off-shore deposits. In their formation the ocean takes part through its waves and currents, and hence they are

more conveniently described in connection with the remarks on oceanic action.

B. Subterranean Waters.

1. **Origin and course of subterranean waters.** — A part of the waters that fall on the earth's surface — on its mountains as well as its plains — sinks through the ground and into the rocks beneath, wherever there are openings or crevices, or looseness of texture, and thus becomes subterranean. The waters usually pass easily through sandstones; but over a clayey or other compact stratum they accumulate, and often make wet springy soil above; or if the stratum is inclined, they may descend to great depths, or come to the light again wherever it outcrops at a lower level. The descending waters sometimes gather into subterranean streams, which have powers of abrasion. Over large areas in some limestone regions, and many volcanic, surface streams are wanting, because of the cavernous recesses; the waters carry on an *underground* system of drainage. Thus come springs, subterranean streams large and small, and copious out-flows beneath the sea-level along coasts.

A region of horizontal limestone abounds in sink-holes, as well as caverns; and sometimes rivers plunge down the openings into the recesses below, and are lost, or emerge again in fuller flow a mile or more away.

Ordinary waters easily erode limestone, because they contain carbonic acid (page 83). Through the joints or fissures the waters find a way downward, and the erosion they produce makes and widens the joints, forming often funnel-shaped sink-holes. At the bottom of the sink-hole the waters work laterally, eroding channels and chambers, in long series and varying directions; and if, later, they succeed in penetrating to a still lower level, another tier of chambers is begun. Undermining also goes on, causing falls of rock, and sometimes large enough to make feeble earth-

The preceding map (reduced from H. C. Hovey's interesting work on American Caverns) represents the passages and chambers of Mammoth Cave, Kentucky. This cave occupies, with its windings, an area of several square miles in the Carboniferous limestone. The length of the caverns in this limestone in Kentucky (a rock 200 to 1000 feet thick) is estimated by Prof. Shaler at 100,000 miles. Luray Cavern, in Luray Valley, Virginia, is comparatively small, but, as described by Mr. Hovey, it is one of the most remarkable in the world, for the beauty of its stalactitic hangings and the grandeur of its subterranean chambers.

In many caverns, bones of the animals that have inhabited them, including sometimes those of Man with his implements of stone or shell or other material, are found buried beneath or within the stalagmite that covers the floor—the perpetual dripping keeping up its constant deposition (pages 37 and 85.)

Caves exist in the elevated coral reefs of the Pacific, which are certainly of comparatively recent origin. One, on the island of Atiu, near Tahiti, has "interminable windings" and many chambers, "with fretwork ceilings of stalactite and stalagmite" (J. Williams). There are others on Oahu, which give a passage to island streams.

The erosion is helped forward (1) by the oxidation of pyrite (page 82) where it is present, the resulting sulphuric acid turning limestone into gypsum; and also (2) by the formation of nitric acid from the nitrogen of the air, which erodes the limestone, making calcium nitrate. The caves of Kentucky and Indiana have afforded a large amount of this nitrate for the making of nitre.

Subterranean waters often become *mineral waters*. They are made *calcareous* by limestones along their course; *saline*, from the saline ingredients of rocks; *sulphureous*, by decomposing iron sulphides; *carbonated*, by any acid, as sulphuric, attacking a limestone and setting carbonic acid free; *chalybeate*, if iron is present in the last process; and *magnesian*, or

of other quality, in connection with the last, when the decomposition of any rock is going forward that can afford the materials, and when the ocean is a source. They may become *warm waters* through the decomposition of pyrite, etc., or through subterranean heat, and may receive vapors and various mineral materials from the depths below.

2. Artesian Wells.—When strata are inclined, and water descends along one of the layers between others that are sufficiently close to confine it, the pressure increases with the descent; so that the water will rise through a boring made down to it, and sometimes in a high jet. The principle is illustrated in Fig. 109, in which *ab* is the water-bearing stratum, *bc* the boring, and *eb* the amount of descent. The height of the jet falls much short of *be*, on account chiefly of the underground friction.

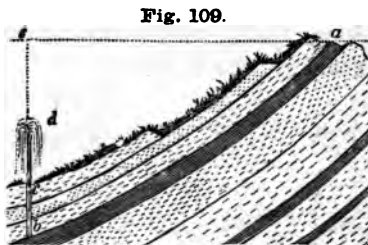


Fig. 109.

Section illustrating the origin of Artesian wells.

Such wells are called *Artesian wells* or *borings*, from the district of Artois in France, where they were early made. The Artesian well of Grenelle in Paris is 1,798 feet deep, and when first made the water darted out to a height of 112 feet. One at St. Louis has a depth of $3,843\frac{1}{2}$ feet, but without getting water, because the region for many miles around is one of horizontal rocks. Such wells are made for agricultural and manufacturing purposes in many dry regions, and they have proved successful even in Sahara.

3. Land-Slides.—*Land-Slides* are of different kinds:—

1. The sliding of the surface earth, or gravel, of a hill down to the plain below. This effect may be caused by the waters of a severe storm wetting the material deeply and giving it *greatly increased weight*, besides loosening its attachment to the more solid mass below.

2. The sliding down a declivity to the plain below of the

upper layer of a rock-formation. This may happen when this upper layer rests on a clayey or sandy layer and the latter becomes very wet and greatly softened by the waters; the upper layer slides down on the softened bed.

3. The settling of the ground over a large area. This may take place when a layer of clay or loose sand becomes wet and softened by percolating waters, and then is pressed out laterally by the weight of the superincumbent layers. But such a result is not possible unless there is a chance for the wet layer to move or escape laterally. Sometimes part of *a wet clayey layer, pressed to one side in this way, is left very much folded*, while the associated sandy layers have their usual regular bedding.

2. The Ocean.

The ocean is vast in extent and vast in the power which it may exert. But its mechanical work in Geology is mostly confined to its coasts and to soundings, where alone material exists in quantity within reach of the waves or currents. In ancient time, when the continents had not their present mountains, and were to a great extent submerged at shallow depths, this work was performed simultaneously over a large part of their surface, and strata nearly of continental area were sometimes formed. In the present age, oceanic action is almost wholly confined to the borders of the continents.

The *saltness of the ocean* gives it a density of 1.0245 to 1.0278, that of pure fresh water being 1. It is slightly the greatest in the tropics, because of the evaporation. A cubic foot weighs about 64 pounds. There are three consequences of the saltness: (1) greater transporting power than fresh water, on account of its density; (2) *much quicker deposition of sediment*, the time required in salt water being *a fifteenth of that* in fresh, on account of the less adhesion of the particles; (3) a supply of common salt and magnesian salts, etc., for making deposits of salts, and for use in chem-

ical changes attending the making of rocks and minerals, it being the largest of mineral springs (p. 28).

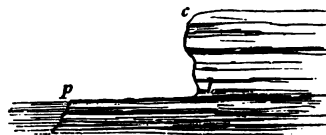
The mechanical effects of the ocean are produced by its waves and currents.

1. Erosion and Transportation.

1. Waves.—*1. General action.*—The force in *oceanic waves* is a constant force. Night and day, year in and year out, with hardly an intermission, they break against the beaches and rocks of the coast; sometimes gently, sometimes in heavy plunges that have the force of a Niagara of almost unlimited breadth. The gentlest movements have some grinding action among the sands, while the heaviest may dislodge and move along, up the shores, rocks many tons in weight. Niagara wastes its power by falling into an abyss of waters: while in the case of the waves the rocks are bared anew for each successive plunge. The waters are often loaded with gravel and sand when they strike, and thus carry on abrasion. Cliffs are undermined, rocks are worn to pebbles and sand, and, through mutual friction, sand is ground to the finest powder. Rocky headlands on windward coasts are especially exposed to wear, since they are open to the battering force from different directions.

2. Level of greatest eroding action.—The eroding action is greatest for a short distance above the height of half-tide, and, except in violent storms, it is almost null below low-tide level. Fig. 110 represents in profile a cliff, having its lower layers, near the level of low tide, extending out as a platform a hundred yards wide. As the tide commences to move in, the waters, while still quiet, swell over and cover this platform, and so give it their protection; and the force of wave-action,

Fig. 110.



Cliff, New South Wales.

which is greatest above half-tide, is mainly expended near the base of the cliff, just above the level of the platform. But for much battering effect a coast should be shelving, so as to raise the waters as they advance. If deep alongside of a cliff, there is simply a rise and fall, with little abrasion.

3. Action landward. — Waves on shallow soundings have some transporting power; and, as they always move toward the land, their action is landward. They thus beat back, little by little, any detritus in the waters, preventing that loss to continents or islands which would take place if it were carried out to sea.

4. Effect on the outline of coasts; No excavation of narrow valleys. — As the action of waves on a coast tends to wear away headlands, and at the same time to fill up bays with detritus, it usually results in making the outline more regular or even. There is nowhere a tendency to excavate narrow valleys into a coast, like those occupied by rivers. Such valleys are made by the waters of the land; for the ocean can work at valley-making only when it has already an open channel for the waters to pass through, and then the valleys are of very great width. If a continent were sinking slowly in the ocean, or rising slowly from it, wave-action would still be attended by the same results; for each part of the surface would be successively a coast-line, and over each there would be the same wearing away of headlands and filling of bays, instead of the excavation of valleys.

2. Tidal currents. — Tidal currents often have great strength when the tide moves through channels or among islands, and then they are a means of erosion and transportation daily in action, wherever there is rock, mud, or sand within their reach.

The *out-flowing* current from bays, or that connected with the ebbing tide, is deeper in its action, and has, therefore, more excavating and more transporting power than the *in-flowing*, or that of the incoming tide. The latter moves on as a great swelling wave, and fills the bays much above their

natural level; but the out-flowing current begins along the bottom before the tide is wholly in, owing to the accumulation of waters, and when the tide changes it adds to the strong current-movement already in progress.

The piling up of the waters in a bay by the tides, or by storms, produces, especially if the entrance is not very broad, a strong out-flowing current at bottom, which tends to keep the channel deep and clear of obstructions.

The in-flowing tide, sweeping along a coast, checks partly or wholly the outflow of the rivers. This causes a deposition of more or less of the detritus which the rivers transport, near or against the shores or flats just beyond the river-channel; and thus it often makes great sand-flats, which encroach on the entrance. If a long point projects on the side of the mouth first reached by the in-flowing tide, the tidal flow may carry the detritus far beyond the river's mouth; but if no such point exists, and the opposite cape is the longer, the detritus will be thrown into the throat of the stream, and the entrance become more or less choked. The river mouths of the Connecticut shore, on the north side of Long Island Sound, along which the in-flowing tide moves *westward*, illustrate well these facts. The two largest of the rivers, the Connecticut and Housatonic, are of the unfortunate kind, as they have no eastern cape, while New Haven, having only very small streams, is much better off, as regards depth of water for entrance, because of a projecting eastern cape.

The *bore* or *eagre* of some great rivers is a kind of tidal flow up a stream. It is produced when the regular rise of the tide in the bay at the mouth of the river is obstructed by the form of the entrance and its sand-banks, together with the outflow of the river, so that the waters are for a while prevented from entering, until, finally, all those of one tide rush in at once, or in a few great waves. The *eagres* of the Amazon, the Hoogly in India (one of the mouths of the Ganges), and the Tsien-tang in China, are among the most remarkable. In the case of the Tsien-tang, the water moves

up stream in one great wave, plunging like an advancing cataract, four or five miles broad and 30 feet high, at a rate of 25 miles an hour. The boats in the middle of the stream simply rise and fall with the passage of the wave, being pushed forward only a short distance; but along the shores there is often great devastation, the banks being worn away and animals sometimes surprised and destroyed.

3. Currents made by winds. — There are also *currents produced by winds*, especially when there are long storms, or when the winds blow for months in one direction. The great currents of the oceans, such as the Gulf Stream, are attributed by some physicists to this source. Such currents, sweeping by a coast, transport from one place to another in their course more or less of the sand of the shores, often making long sand-flats or spits off the shores to leeward, as on the south coast of Long Island and the more southern parts of the Atlantic border. The action is aided by the tidal currents. In some cases the drifted sand may be in part carried back again when the season changes to that in which the wind blows from the opposite direction. Other portions of detritus may be carried by them away from the land and distributed in the deeper waters.

The *great currents of the ocean* are for the most part so distant from the borders of the continents that little detritus comes within their reach. As these currents have great depth, — often a thousand feet or more, — their course is determined partly by the deep-water slopes of the submerged border of a continent, so that when the border is shallow for a long distance out (as off New Jersey and Virginia, where this long distance is even 50 to 80 miles), the main body of the current is equally remote. Wherever it actually sweeps close along a coast, it may bear away some detritus to drop it over the bottom in the neighboring waters. The flow of the Gulf Stream against the submerged slope of the oceanic basin (about three-fourths of a mile per hour) is sufficient to keep the bottom free from loose detritus. Verrill has suggested

that the burrowing of fishes for food aids, by loosening the material.

The oceanic currents flowing from polar seas produce important effects by means of the icebergs which they bear into warmer latitudes. These icebergs are sometimes freighted with earth and rocks; and wherever they melt, they drop all to the ocean's bottom. The sea about the Newfoundland banks is one of the regions of the melting icebergs; and there is no doubt that vast submarine accumulations of such material have been there made by this means. It has been suggested that the banks may have been thus formed.

2. Distribution of material, and the formation of marine and fluvio-marine deposits.

1. Origin of material.—The material used by the waves and currents is either — (1) the stones, gravel, sand, clay, or earth produced by the wear of coasts; or (2) the detritus brought down by rivers and poured into the ocean, as explained on page 98.

The latter, in the present age, is vastly the most important. But in the earlier geological ages, when the dry land was of small extent, rivers were small and were but a feeble agency. The ocean had then vastly greater advantages than now, because, as stated on page 106, the continents were mostly submerged at shallow depths, or lay near tide-level within reach of the waves and currents.

The decomposition or disintegration of exposed rocks through the agency of air and moisture must have aided in degradation formerly more than now, since in Paleozoic time and earlier, *carbonic acid gas*, the chief agent of destruction, was much more abundant in the atmosphere than it is now. This agent is carried to the earth's surface by the rains, and it is still effective in the decomposition of granite, gneiss, and many other rocks.

2. Forces in action.—In the distribution of the material, the waves and marine currents have either worked alone, in the manner explained on the preceding pages, or in conjunction with river-currents wherever these existed.

3. Marine formations.—The marine formations are of the following kinds:—

Beach-accumulations.—Beaches are made of the material borne up the shores by the waves and tides and left above low-tide level. This material consists of stones or pebbles, sand, mud, earth, or clay. It is *coarse* where the waves break heavily, because, although trituration to powder is going on at all times, the powerful wave-action and the undercurrent carry off the finer material into the off-shore shallow waters, where it settles over the bottom or is distributed by currents. It is *fine* where the waves are gentle in movement, as in sheltered bays, or estuaries, the triturerated material remaining in such places near where it is made, and often being the finest of mud.

Sand-banks, or reefs; Shallow-water accumulations.—Shallow-water accumulations may be produced in bays, estuaries, or the inner channels of a coast, and over the bottom outside. They consist usually of coarse or fine sand and earthy detritus, but may include pebbles or stones when the currents are strong. The material constituting them is derived from the land through the wearing and transporting action either of the waves and currents, or of rivers. The accumulations may increase under wave-action in shallow water, until they approach or rise above low-tide level, and then they form sand-banks. Such sand-banks keep their place in the face of the waves, for the same reason as the platform of rock mentioned on page 107 and illustrated in Fig. 110.

Fluvio-marine formations.—Most of the accumulations in progress on existing shores, whether sand-banks, or estuary, or off-shore deposits, especially about well-watered continents, contain more or less of river-detritus, and are modified in their forms by the action of river-currents. Along the whole

eastern coast of the United States south of New England, and on all the borders of the Gulf of Mexico, the formations in progress are mainly *fluvio-marine*, — that is, the combined result of rivers and the ocean. The coast-region on the continent is now slowly widening through this means, and has been widening for an indefinite period: This coast-region is low, flat, often marshy, full of channels or sounds; and facing the ocean there is a barrier-reef, made of sand.

The rivers pour out their detritus especially during their floods, and the ocean's waves and currents meet it as the tide sets in, with a counter-action, or one from the seaward; and between the two the waters, as they lose their velocity, drop the detritus over the bottom. When the river is very large and the tides feeble, the banks and reefs extend far out to sea. The Mississippi thus stretches its many-branched mouth (page 101) fifty miles into the Gulf. When the tide is high, sand-bars are formed; and the higher the tides the closer are the sand-bars to the coast. When the stream is small, the ocean may throw a sand-bank quite across its mouth, so that there may be no egress to the river-waters except by percolation through the sand, or, if a channel is left open, it may be only a shallow one.

3. Structure of the formations.

Beach-formations are very irregular in stratification in their upper portions, where they are made by the toss of the waves combined with drifting by the winds. The layers—as shown in Fig. 22 *d*, page 45 — have but little lateral extent, and change in character every few feet. But the sloping part swept by the waves below high-tide level is very evenly stratified parallel to the surface; and since this surface pitches at an angle usually of 5° to 15° , the beach-made beds have the same pitch or dip. The coarser beaches have the highest slopes.

The *sand-banks* and *reefs* made in shallow waters along a

coast have a regular and more horizontal stratification, and are mostly composed of sand with some beds of pebbles. They often vary much every mile or every few miles. The extent and regularity of level of the submerged area off a coast will determine in a great degree the extent to which the uniformity of stratification may extend; and in this respect the former geological ages, as observed on page 106, had greatly the advantage of the present.

Ripple-marks (Fig. 24, page 46) are made by the wash of the waters over a sand-flat or up a beach, or over the bottom within soundings; also by wave-action where the waters are not flowing. *Rill-marks* (Fig. 25) are produced when the return waters of a tide, or of a wave that has broken on a beach, flow by an obstacle, as a shell or pebble, and are piled up a little by it so as to be made to plunge over it, and so erode the sands for a short distance below the obstacle. The *cross-bedded* structure results from the rapid inward movement of the tide, or the flow of any current, over a sandy bottom: it makes a series of inclined layers by the piling action dipping in the direction of the movement; when the movement ceases, the detritus may deposit horizontally for a while; and afterward the flow and its results may be repeated. When there are plunging waves accompanying the rapid flow of a current, the obliquely laminated layer is broken up into short wave-like parts, — as in the *flow-and-plunge* structure (page 45).

The imbedded shells and other animal relics in a beach are commonly broken; those in the bays or off-shore shallow waters out of the reach of the waves may be unbroken, or may lie as they did when living; but if the waters are not so deep but that the shells or corals are exposed to wave-action, they may be broken or worn to powder, and enter in this state into the formation in progress. (See further, page 79, the remarks on the formation of limestone from shells or corals.)

Deposits of broken shells under water are sometimes made by fishes that have taken the animals for food. Such

beds made by fishes answer to the shell-heaps of human origin.

In the sands of beaches near low-tide level, borings of Sea-worms, or of some Mollusks or Crustaceans, may exist.

3. Freezing and Frozen Waters.

A. Freezing Water.

As water in the act of freezing expands after reaching $39^{\circ} \cdot 2$ F. (4° C.), freezing in the seams of rock opens the seams and tears masses asunder. The expansion on reaching 32° F. is 1-35th lineally, and the density is diminished to 0.92. The results of expansion are most marked in rocks that are much fissured, or intersected by joints, or that have a slaty or laminated structure. As the action continues through successive years and centuries, it often results in great accumulations of broken stone. The slope, or *talus*, of fragments at the foot of bluffs of trap or basalt is often half as high as the bluff itself. In tropical countries, bluffs have no such masses of ruins at their base.

Granular rocks, whether crystalline or not, when they readily absorb water, lose their surface-grains by the same freezing process. Granite, as well as porous sandstones, may thus be imperceptibly turning to dust, earth, or gravel. In Alpine regions this action may be incessant.

Alternate freezing and thawing produces (as explained by Kerr) a movement of earth and gravel on slopes, with re-arrangements of the materials.

B. Frozen Water.

The effects of ice and snow are conveniently considered under three heads: 1. *The ice of lakes and rivers*; 2. *Glaciers*; 3. *Icebergs*.

1. Ice of Lakes and Rivers.

The ice of lakes and rivers often forms about stones along their shores; and sometimes over those of the bottom (then called *anchor-ice*), making them part of the mass; and other stones sometimes fall on shore-ice from overhanging bluffs. The ice serves as a float to the stones; and in times of high water, or floods, it may carry its burden high up the shores, or over the flooded flats, to leave them there as it melts. Large accumulations of bowlders are sometimes made, by this means, on shores far above the ordinary level of the waters.

2. Glaciers.

1. **Glaciers are ice-streams**, or rivers in which the moving material is *frozen* instead of *liquid* water.

Like large rivers, they ordinarily have their sources in high mountains, and descend along the valleys; but (1) the mountains are such as take snow from the clouds instead of rain, because of their elevation; and (2) they must be high and extensive enough to take annually a large supply of snow from the clouds, so that the snow may accumulate to a great depth; and (3) the region must be one of sufficient precipitation.

Like large rivers, many tributary streams coming from the different valleys unite to make the great stream.

As with rivers, their movement is dependent on gravity, or the weight of the material; but the average rate of motion, instead of being several miles an hour, is generally in summer but 10 to 18 inches a day, or a mile in 18 to 20 years. 12 inches a day corresponds to a mile in $14\frac{1}{2}$ years. The rate is half less in winter than in summer.

As with rivers, the central portions move most rapidly, the sides and bottom being retarded by friction.

The snow of the mountain-tops, called the *névé*, which is

perhaps hundreds of feet deep, becomes compacted and converted into ice mainly by its own weight, through the aid of water penetrating it derived from partial melting; and thus the *glacier* begins. Through the occasional melting and freezing, the change to ice is made more complete. As the glacier starts on its course, the clouds furnish new snows to keep up the supply and help press on the moving mass.

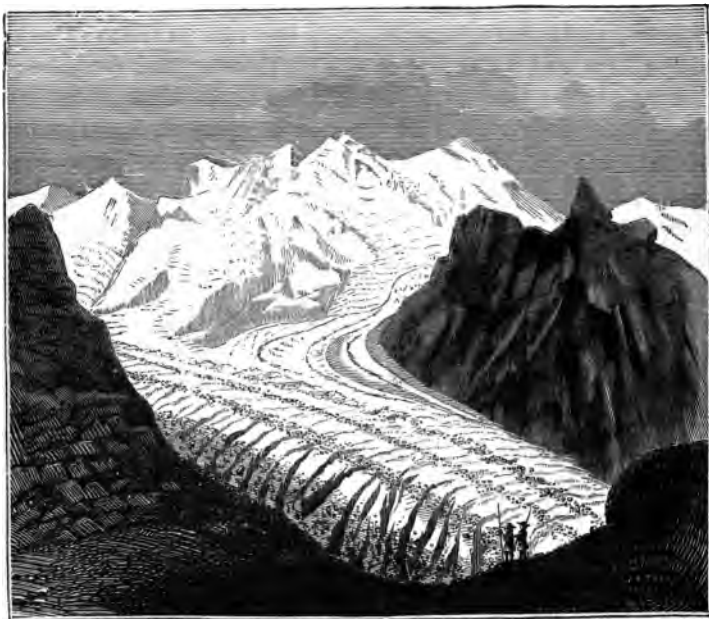
2. Descent below the snow-line. — The height, in the Alps, of the snow-line, or that below which the snow annually precipitated melts during the year, is 8,000 feet on the north side of the Alps, and 8,800 feet on the south side; and the *glacier* descends below this line 4,500 to 5,300 feet. The ice resists the melting heat of summer because of its mass, like the ice in an ice-house. Though starting where all is white and barren, it passes by regions of Alpine flowers, and often continues down to a country of gardens and human dwellings before its course is finally cut short by the climate. Thus, the *Bois glacier*, an upper portion of which is called the *Mer de Glace*, rises in Mont Blanc and other neighboring peaks, and terminates, like two other glaciers, in the vale of Chamouni. In a similar manner, two great glaciers descend from the Jungfrau and other heights of the Bernese Alps to the plains of the Grindelwald Valley just south of Interlachen.

Fig. 111 represents one of the ice-streams of the Mount Rosa region in the Alps, from a view in Professor Agassiz's work on Glaciers. It shows the lofty regions of perpetual snow in the distance; the bare rocky slopes that border it, later on its course; and the many crevasses that intersect the surface of the ice-stream.

3. Fractures attending the movement. — **Crevasses.** — Every valley has its ridgy sides, its sharp turns, its abrupt narrowings and widenings, its irregular bottom; and the stiff ice, compelled to accommodate itself to these irregularities, has, consequently, profound *crevasses* made usually along its borders, besides multitudes of cracks that are not visible at the surface; also, still profounder chasms when wrenched, or

stretched, in turning some point; longer crevasses, crossing even its whole breadth, when the ice plunges down a steep place in an ice-cascade, or when, on escaping from a narrow gorge, it moves off freely again with increase of slope. Again, it may lose all its crevasses, from their closing up, when the rate of motion is lessened by diminished slope or otherwise.

Fig. 111.



Glacier of Zermatt, or the G6rner Glacier.

4. Glacier torrent.—The melting of the glacier, especially during the warm season, gives origin to a stream of water flowing beneath it, which becomes gradually a torrent of considerable size, and finally emerges to the light from beneath the bluff of ice in which the glacier terminates. Thence it continues on its rocky course down the valley.

5. Method of movement.—The *capability of motion* in a glacier is (1) dependent partly on a degree of plasticity in ice. Ice may be made, through pressure, to copy a seal, or may be drawn out into cylinders; or, if a slab is supported only at the sides, it will become bent downward, through gravity.

(2) It is also due in part to the facility with which ice breaks. The ice afterward becomes a solid mass when the broken surfaces are brought into contact. This *re-gelation* was first noticed by Faraday. It is easily tried by breaking a lump of ice and bringing the surfaces again into contact: if moist, as they are at the ordinary temperature, they at once become firmly united. A glacier moves on and accommodates itself to its uneven bed by bending or breaking; and, however fractured, it may, when the movement slackens and the parts are pressed together, become as solid as before.

Again (3), the ice is everywhere penetrated by water during nearly all the year, and this diminishes the friction within the mass. This moisture comes from above, but is added to below because of the heat of friction. The greater amount in summer is a cause of the more rapid movement then.

Again (4), a glacier may here and there, at times, slide along its bed, yet only portions at a time.

6. Transportation by Glaciers.—Moraines.—Glaciers become laden with stones and earth falling from the heights above, or coming down in crushing avalanches of snow and stones. The stones and earth make a band along either border of a glacier, and such a band is called a *moraine*. When two glaciers unite, or a tributary glacier joins another, they carry forward their bands of stones with them; but those on the uniting sides combine to make one moraine. A large glacier, like that in Fig. 111, may have many moraines,—or one more than the number of its tributaries. Some of the masses of rock on glaciers are of immense size. One is mentioned containing over 200,000 cubic feet,—which is equivalent in cubic contents to a building 100 feet long, 50 wide, and 40 high.

The ice also gathers up masses of rock from any hillocks in the surface beneath it, easily detaching and bearing off great slabs when the rocks are jointed or fractured.

In the lower part of a glacier the several moraines lose their distinctness through the melting of the ice; for this brings to one level what was distributed through a considerable part of its former thickness, and the surface, therefore, becomes covered with earth and stones. The bluff of ice which forms the foot of a glacier is often a dirty mass, showing little of its real icy nature, in the distant view.

The final melting leaves all the earth and stones in unstratified heaps or deposits, to be further transported, eroded, and arranged, by the stream that flows from the glacier.

7. Erosion by Glaciers.—A glacier laden with stones will have stones in its lower surface and sides, as well as in its mass. As it moves down the valley, it consequently abrades the exposed rocks over which it passes, smoothing and polishing some surfaces, covering others closely with parallel scratches, and often ploughing out broad and deep channels, besides having its abrading bowlders scratched or polished.

Deep ploughing is accomplished only (1) when the rock beneath is soft or fragile, or (2) when it is jointed, rifted, or laminated. In the latter case the action is *rending*, rather than abrading, and by this means the larger part of the direct excavation by glaciers has been done.

The rocky ledges over which the ice has long moved are often reduced to rounded prominences; they then look, in the distance, like groups of crouching sheep, and hence have been called, in French, *roches moutonnées*. They are exhibited on a grand scale in some of the valleys of the high ranges along the summit of the Rocky Mountains, where were formerly extensive glaciers; and Fig. 112 represents one of the scenes, in the region of the "Mountain of the Holy Cross" (the remoter summit near the centre of the view), as photographed by the photographer of the Expedition under Dr. Hayden. Further, the stones in the ever-shifting ice wear one another,

and may thereby become rounded at the angles ; and the very fine dust thus made is carried down by the waters along the crevasses to make beds of clay or earth, and give a milky hue to the streams flowing from a glacier region.

Fig. 112.



View on Roche-Moutonnée Creek, Colorado.

Glaciers deepen and widen the valleys in which they move. But in this work they are aided by the frosts, avalanches, and especially by the torrents beneath the glacier.

8. Glacier regions. — The best known of Glacier regions are those of the Alps, in one of which Mont Blanc stands, with its summit 15,760 feet above the sea. There are glaciers also in the Pyrenees, the mountains of Norway, Spitzbergen, Greenland, and other Arctic regions, in the Caucasus and Himalaya, in the Southern Andes, in the Coast range and

Rocky Mountain summits of British America. Greenland is a great glacier-covered land, sending many large streams through the fiords of the border region to the polar seas.

3. Icebergs.

When glaciers, like those of Greenland, terminate in the sea, the icy foot becomes broken off from time to time, through the varying movement of the tides; and these fragments of glaciers, floated away by the sea, are *icebergs*. The geological effects of icebergs have been stated on page 111. Sea-shore ice sometimes carries stones and gravel far out to sea.

4. Formation of Sedimentary Strata.

The following is a brief recapitulation of the explanations of the origin of deposits given in the preceding pages. Igneous and other crystalline rocks are not here included.

1. Sources of material.—The material of sedimentary rocks, excluding limestones, has come mainly from the degradation of pre-existing rocks. But another part (as that of limestones, or infusorial earth) has been taken up from a state of solution in the ocean or in fresh waters, through the agency of life; yet the waters have received the ingredients from the rocks, either when the ocean first began to exist, or subsequently through the dissolving action of streams on exposed rocks (page 111).

The Archæan rocks were the original source; and in Eastern North America, where the formations of the Green Mountains and Appalachians have great thickness, Archæan ridges existed both over New England and on the Atlantic borders.

2. Means of degradation.—The principal means of degradation are the following: 1. Erosion by moving waters, either those of the sea or land (pages 90, 107); 2. Erosion by ice, either that of glaciers, icebergs, or ordinary snow and ice

(page 120); 3. Pressure of the water descending into fissures; 4. Forming of substances, for example oxide of iron, in cracks, this tending to open and deepen the cracks; 5. Growth of rootlets, roots, and trunks of trees, in crevices, resulting in opening and tearing apart rocks, and often producing extensive destruction of rocks, especially when they are jointed; 6. Freezing of water in fissures (page 115); 7. Chemical decomposition of one or more of the ingredients of a rock, in the course of which process the rock becomes crumbled or reduced to earth; 8. Removal by solution, as of limestones by carbonated waters; 9. Undermining of rocks by any method; 10. Expansion and contraction by heat (page 128.)

3. Formation of deposits. — The principal methods by which deposits have been formed are the following: —

1. By the waters of the sea. — 1. Through the sweep of the ocean over the continents when barely or partly submerged, — making (a) sandy or pebbly deposits near or at the surface where the waves strike, or at very shallow depths where swept by a strong current; (b) argillaceous or shaly deposits near or at the surface, where sheltered from the waves; and also, at considerable depths, out of material washed off the land by the waves or currents; but not making (c) coarse sandy or pebbly deposits over the deep bed of the ocean, as even great rivers carry only silt to the ocean; and not making (d) argillaceous deposits over the ocean's bed except along the borders of the land, unless by the aid of a river like the Amazon; in which case, still, the detritus is mostly thrown back on the coast by the waves and currents.

2. Through the waves and currents of the ocean acting on the borders of the continent; the results are the same as above, except that the beds so made have less extent.

3. Through living species, and mainly Mollusks, Radiates, and Rhizopods, affording calcareous material for strata; and Diatoms and some Protozoans, siliceous material. Most rocks made of corals and the shells of Mollusks have required the help of the waves, at least to fill up the interstices.

2. *By the waters of lakes.* — Lacustrine deposits are essentially like those of the ocean in mode of origin, unless the lakes are small, when they are like those of rivers.

3. *By the running waters of the land.* — 1. Filling the valleys with alluvium and other fluvial deposits, and moving the earth from the hills over the plains (page 98). 2. Carrying detritus to the sea or to lakes, to make, in conjunction with the action of the sea, or lake-waters, delta and other sea-shore accumulations (pages 99, 100).

4. *By frozen waters.* — A. Acting in the condition of *glaciers*, and thus: 1. Spreading the rocks and earth of the higher lands over the lower, and, in the process, bearing onward blocks of great size, as well as finer material (pages 119, 120). 2. Distributing rocks and earth in lines or moraines. — B. Acting as *icebergs*; and, in this condition, transporting stones and earth to distant parts of the ocean, as from the Arctic regions to the Newfoundland Banks, and so contributing to deep or shallow water or shore sedimentary accumulations, distinguished by their containing huge blocks of stone, besides pebbles, and earth.

V. — HEAT.

1. Sources of Heat.

The crust of the earth derives heat from *three* sources: 1. The sun, an external source; 2. The earth's heated interior; 3. Chemical and mechanical action.

1. *The Sun.* — This agency is peculiar in being regularly intermittent, through the alternations in the seasons, in day and night, in the time of aphelion and perihelion, and in the eccentricity of the earth's orbit. The amount of heat imparted to the earth varies also with the density of the atmosphere, the denser atmosphere absorbing more heat; and it was greater in early time, when the proportion of carbonic acid and of moisture was greater than now. The following

are some of the causes to which change in *climate* has been attributed:—

1. A gradual diminution in the heat of the sun through the geological ages.

2. Variations in the condition of the sun's exterior, causing periodical alterations in the amount of heat radiated, and thus producing alternating cold and warm eras.

3. Variations in the level of the earth's surface, the climate becoming changed when extensive regions have been lifted into mountains, as during the Tertiary age, or when great areas in high latitudes have been elevated to a less extent; and especially when the change in the level of the land or sea-bottom has diverted the oceanic currents from one course to another. Elevating the sea-bottom between Europe and Greenland would shut out the warm Gulf Stream from the Arctic region and increase its cold. For, according to Croll's calculations, this stream contributes to the North Atlantic Ocean 77,479,650,000,000,000 foot-pounds of energy, in the form of heat, per day. Such a change might, therefore, make a glacier-cold climate for the northern hemisphere. On the contrary, a subsidence opening Behring Straits for the free passage of the tropical current of the Pacific would ameliorate the arctic climate.

4. Variations in the eccentricity of the earth's orbit. The earth, through all such variations, derives the same amount of heat annually from the sun, but not the same for the winter as for the summer. The maxima of eccentricity are unequal, and are passed once in 100,000 to 200,000 years. The earth is at present near a minimum, and the distance from the sun is about 93·9 millions of miles in aphelion (which comes now in summer), and nearly 90·9 millions in perihelion—the difference, 3 millions. About 110,000 years since, a maximum occurred, with the aphelion and perihelion distances 96·65 and 88·15 millions of miles—the difference, 8½ millions; and 850,000 years since, an extreme maximum, with these distances, 99·3 and 85·5 millions—the difference

13.8 millions of miles. When the aphelion comes in winter, the cold of the winters is increased, the amount of heat received being inversely as the square of the distance (which ratio gives for the heat in winter, during the extreme maximum referred to, about $\frac{5}{8}$ ths that now received in that season); and, also, the winter half of the year between the equinoxes will be, at the extreme maximum, 36 days longer than the summer half (now, it is 8 days shorter); at the same time, the summers will be proportionally hotter, but, in the same proportion, shorter. In the southern hemisphere the reverse, in each respect, is true. The cold of a Glacial era has been thus accounted for, and also the warmth of warm eras, by Croll; but others reject the theory. It admits of two Glacial eras in the same hemisphere during one prolonged time of maximum, since the aphelion has a cycle of only 21,000 years; but it makes the southern Glacial era to come 10,500 years after the northern. Further, the ice of a Glacial era tends to intensify and perpetuate the glacial condition, since it can take and radiate, even in the sunshine, no temperature above that of the freezing-point.

5. A change in the earth's axis has been regarded as a source of variation in climate. But calculations by Mr. G. H. Darwin, Haughton, and others, have shown that no such change can have taken place sufficient for any marked result.

2. Internal Heat.—The fact of a high heat in the earth's interior is established in various ways.

1. The form of the earth is a spheroid, and a spheroid of just the shape that would have resulted from the earth's revolution on its axis, provided it had passed through a **state of complete fusion**, and had slowly cooled over its exterior. Hence is drawn the conclusion that it has passed through such a state of fusion, **which** is strengthened by the other evidence here given. Another conclusion also follows: namely, that the **earth's axis** had the same position (or, at least, very nearly **the same**) when cooling began as now. There is no **evidence** that there has been at any time a change.

2. In deep borings for water and in shafts sunk in mining, it has been found that the temperature of the earth's crust increases, on an average, *one degree* of Fahrenheit for every 64 feet of descent. The rate of 1° F. for 64 feet of descent, in the latitude of New York, would give heat enough to boil water at a depth of 10,000 feet; and at a depth of about 35 miles the temperature would be $3,000^{\circ}$ F., or that of the fusing-point of iron. Since, however, the fusing temperature of any substance increases with the pressure, the depth required before a material like iron would be found in a melted state would be much greater than this. Experiments on the temperature in artesian borings have to guard against error from the heat caused by chemical changes in the rocks below, such as decompositions of sulphides.

3. The great Pacific Ocean has nearly a complete girt of volcanoes, extinct or active; and all of its many islands that are not coral are wholly volcanic islands, — excepting New Zealand and a few others of large size in its southwest corner. Volcanoes occur along many parts of the Andes from Tierra del Fuego to the Isthmus of Darien, in Central America, in Mexico, California, Oregon, and beyond; in the Aleutian Islands on the north; in Kamtchatka, Japan, the Philippines, New Guinea, New Hebrides, and New Zealand on the west; and on Antarctic lands both south of New Zealand and of South America. The volcanic region thus bounded is equal to a whole hemisphere; and, besides, there are volcanoes in many parts of the other hemisphere. Outlets of fire so extensively distributed seem to indicate that there is, or must formerly have been, some universal seat of fire beneath.

4. The flexures which the earth's crust and its strata have undergone over regions of continental extent, and even as late as the Cenozoic, indicate that there have been, up to the middle Cenozoic, if not later, as great regions of liquid rock beneath the earth's crust.

3. Chemical and Mechanical action. — In the upturning and

flexure of rocks attending mountain-making there have been movements on a grand scale ; and, through the transformation of this motion into heat, the rocks have received in some cases a high temperature, sufficient to promote, through the moisture present, the consolidation of rocks, and even their crystallization or metamorphism ; and also, in the view of Mallet, their fusion on a scale grand enough to originate volcanoes. This is probably one chief source of the heat through which the metamorphism and consolidation of rocks have been produced, the other chief source being the internal heat.

Heat is produced by condensation : as when vapors are condensed, or become liquid or solid ; when liquids (as water) become solid ; when oxidation or other like change takes place, as when pyrite oxidizes (p. 82), — a process that has set fire to beds of coal.

2. Effects of Heat.

The following are the effects of heat here considered : —

1. *Expansion and contraction.*
2. *Igneous action and results.*
3. *Metamorphism.*
4. *Formation of veins.*

5. The heat of the globe is also one of the causes of earthquakes, of change of level in the earth's crust, and of the elevation of mountains : these subjects are considered in the following chapter. It is an important agent also in all chemical changes.

1. Expansion and Contraction.

(1) Heat from any subterranean source penetrating upward may cause *wide changes of level*. Lyell has calculated that a mass of sandstone a mile thick, raised in temperature to 1,000°

F., would have its upper surface elevated 50 feet. Fractures and displacements would be likely to attend such movements. (2) The changing heat of the day, which in some countries amounts to 80° F. or more, and also that of the seasons, is a force always at work. The expansion and contraction may gradually move blocks of rock from their places. It will move the heated side of the block outward; and if this outer part so moved cannot, because of any wedging or the friction at the edges, return with the succeeding contraction, the mass will move to it or have its edges fractured. The Bunker Hill obelisk at Charlestown in Massachusetts has been proved to swing back and forth with the passage of the sun over it. (3) The alternating action of expansion and contraction peels off the grains or outer surface of rocks, and is a prominent means of obliterating glacier markings.

Shrinkage-cracks. — (1) In the cooling of liquid rocks shrinkage-cracks are produced, and thence come the columnar structure of trap, basalt, etc. (page 48). (2) Similar columnar forms are sometimes produced in sandstone after heating, though in general only irregular cracks result. (3) Heat penetrates rocks over wide regions wherever metamorphism is in progress; and the subsequent cooling and contraction may leave multitudes of fractures, in long lines or in reticulations, the subsequent filling of which may make veins.

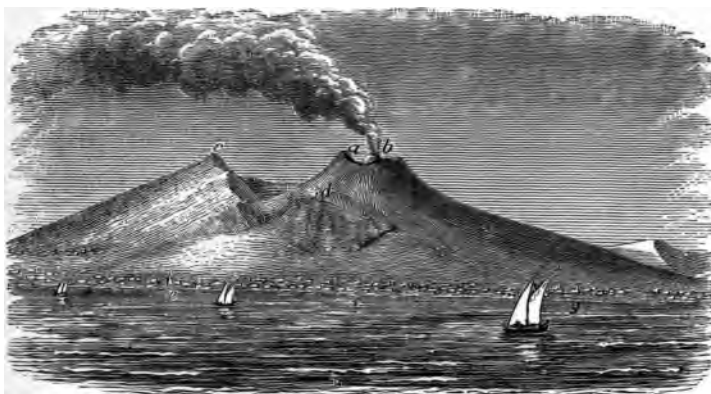
Drying is another source of shrinkage-cracks. It makes the shallow mud-cracks (page 46), the deep soil-cracks, yards in depth, in countries of fertile prairies that have a long hot and dry season, and may produce far deeper joint-like cracks in mud-made rocks (shales and argillaceous sandstones) as they become slowly dried from subterranean heat. Further, the drying of beds produces a sinking of the surface. A soft mud may contract to a tenth of its bulk. All mud-beds will suffer a large diminution in thickness on drying; and when under overlying strata the pressure may prevent shrinkage-cracks from forming.

2. Igneous Action and Results.

A. General Nature of Volcanoes and their products.

Volcanoes are mountain-elevations of a somewhat conical form, which have a crater at centre, and eject, from time to time, streams of melted rock. If the fire-mountain has at present no active fires within, and is emitting no vapors, it is said to be *extinct*.

Fig. 113.



MOUNT VESUVIUS: from a sketch by the author in June, 1834. — *a*, the cone; *b*, summit cinder-cone; *c*, Somma, part of former outline of crater; *d*, Hermitage (now Observatory); *e*, Portici; *f*, Herculaneum; *g*, Torre del Greco. For Map, see p. 398.

The cavity or pit in the top of a volcanic mountain, called the *crater*, where the lavas may often be seen in fusion, is sometimes thousands of feet deep, but may be quite shallow; and in extinct volcanoes it is often wholly wanting, owing to its having been left filled when the fires went out.

The liquid rock issuing from a crater, and the same after becoming cold and solid, is called *lava*.

An active *crater*, even in its most quiet state, emits *vapors*. These vapors are mostly simple steam, or aqueous vapor; but in addition there are usually sulphur gases, and sometimes carbonic acid and hydrochloric acid.

In a time of special activity fiery jets are sometimes thrown up to a great height, which are made of red-hot fragments, — the fragments of great bubbles of lava produced by the escaping vapors. The fragments cool as they descend about the sides of the crater, and are then called *cinders*.

When a shower of rain, or of moisture from the condensed steam, accompanies the fall of the cinders, the result is a mud-like mass, which dries and becomes a brownish or yellowish-brown layer or stratum, called *tufa*. Tufa is often much like a soft coarse sandstone, except that the materials are of volcanic origin.

The materials produced by the volcano are, then — 1. *Lavas*; 2. *Cinders*; 3. *Tufas*; 4. *Vapors* or *Gases*, which are mostly *vapor of water*, partly *sulphur gases*, and in some cases also *carbonic acid*, *hydrochloric acid*, and some other materials.

The *lavas* are of various kinds. They are more or less cellular; sometimes light cellular, like the *scoria* of a furnace; but more commonly heavy rocks, with some scattered ragged cellules or cavities through the mass. A stream of lava of this more solid kind, in a crater, has often a few inches of *scoria* at top, — as a running stream of syrup may have its scum or froth. The most of the *scoria* has this scum-like origin. *Pumice* is a very light grayish *scoria*, full of long and slender parallel air-cells.

The black and brown lavas having high specific gravity (above 2.8) are doleryte and related kinds containing much pyroxene or hornblende; while the gray or light-colored kinds, like the trachytes (below 2.7 in specific gravity), consist chiefly of a feldspar (see p. 37).

A volcanic mountain is made out of the ejected materials; either — (1) out of lavas alone; or (2) of cinders alone; or (3)

of tufas alone; or (4) of alternations of two or more of these ingredients. As the centre of the mountain is the centre of the active fires, the ejections flow off or fall around it, and hence the form of a volcanic peak necessarily tends to become conical.

The average angle of slope of a *lava-cone* is from 3° to 10° ; of a *tufa-cone*, 15° to 30° ; of a *cinder-cone*, 30° to 42° ; of mixed cones, intermediate inclinations according to their constitution.

The ordinary slope of a cinder cone is shown in Fig. 113. Etna, about 10,000 feet high, and Mount Loa of Hawaii, nearly 14,000 feet, consisting mainly of lava streams, have an average slope of less than 10 degrees. The form of a cone with a slope of 7 degrees — which is the average for the Hawaiian volcanoes — is shown in Figs. 114, 115. Fig. 114 has a pointed top, like Mount Kea, and Fig. 115 a rounded outline, like Mount Loa, whose form is that of a very low dome.

Fig. 114.

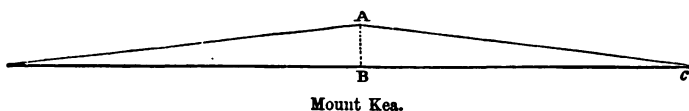
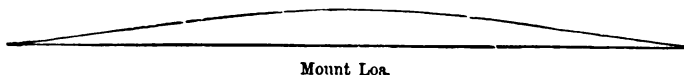


Fig. 115.



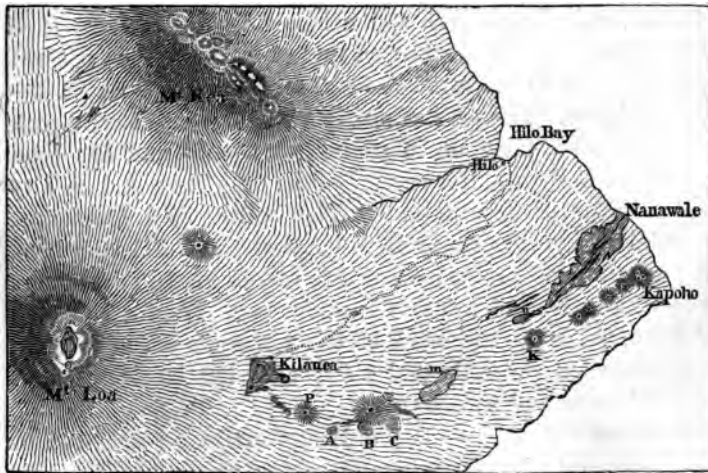
The highest of volcanic mountains on the globe are the Aconcagua peak in Chili, 23,000 feet, and Sorata and Illimani, in Bolivia, each over 24,000 feet. The former appears to be still emitting vapors, showing that the fires are not wholly extinct. The mountains *Shasta*, *Hood*, *St. Helen's*, and others in California and Oregon, are isolated volcanic cones

11,000 to 14,400 feet high, the last being the height of Mount Shasta. The average slope of the upper half of Mount Shasta is about 27° . The slopes of most of the lofty volcanoes of the Andes are between 25° and 34° .

B. Volcanic Eruptions.

The process of eruption, though the same in general method in all volcanoes, varies much in its phenomena. The funda-

Fig. 116.



Map of part of Hawaii.

mental principles are well shown at the great craters of Hawaii, the southeasternmost of the Hawaiian (or Sandwich) Islands.

1. Hawaiian Volcanoes. — *1. General description.* — Hawaii is made up mainly of three volcanic mountains, — two, Mount Loa and Mount Kea (Figs. 114, 115, p. 132), nearly 14,000 feet high; and (the western), Mount Hualalai, about 10,000 feet. Mount Kea is alone in being extinct.

Mount Loa has a great crater at top, and another independent one 4,000 feet above the level of the sea (at P, Fig. 117). The latter is the famous *Kilauea*, called also *Lua Pélé* or Pélé's pit, Pélé being, in the mythology of the Hawaiians, the goddess of the volcano.

The accompanying map of the southeastern portion of Hawaii, Fig. 116, shows the positions of Mount Loa and Mount Kea, and of the crater of Kilauea, besides other craters at the summit of Mount Loa, and at P, A, B, C, K, and east of K.

2. *Kilauea*. — The crater of Kilauea is literally a pit. It is three miles in greatest length, and nearly two in greatest breadth, and about seven and a half miles in circuit. It is large enough to contain Boston proper to South Bridge, three times over, or to accommodate 400 such structures as St. Peter's at Rome. The pit has nearly vertical sides of solid rock (made of lavas piled up in successive layers), and has been 1,000 feet in depth after several of its eruptions, and 400 to 600 previous to its eruptions. The bottom is a great area of solid lava, with one or more lakes or pools of liquid lava, or crater-like openings, from which vapors rise. The largest lake was, in 1840, 1,000 feet in diameter. The interior may be surveyed from the brink of the pit, even when in most violent action, as calmly and safely as if the landscape were one of houses and gardens.

3. *Action in Kilauea*. — The ordinary action, as well exhibited in several great eruptions, is simply this. The lavas in the active pools are in a state of ebullition, jets rising and falling as in a pot of boiling water, — with this difference, that the jets are 30 to 100 feet high. Such jets, in lava as well as water, arise from the effort of vapors to escape; in water the vapor is steam derived from the water itself; in lavas it is chiefly steam from waters that have gained access to the fires, but also gases derived from materials in the lavas, or from depths below.

The lavas of the pools or lakes overflow at times and spread in streams across the great plain that forms the bottom of the

crater. In times of great activity the pools and lakes are numerous, the ebullition incessant, the jets higher, and the overflowings follow one another in quick succession.

4. Cause of eruption. — By these overflows the pit slowly fills. In the intervals between 1823 and 1832, and 1832 and 1840, the bottom was raised 400 feet or more above the lowest level, so that the depth was reduced from 1,000 to 600 feet or less. The addition of 400 feet increased 400 feet the height of the central column of liquid lava of the crater, and caused a corresponding increase of pressure against the sides of the mountain. The amount of this pressure is at least *two and a half times* as great as that which an equal column of water would produce. The mountain should be strong to bear it. The lavas at such times may be in a state of violent activity, and a large addition to the pressure against the sides of the mountain comes from the force of the imprisoned vapors.

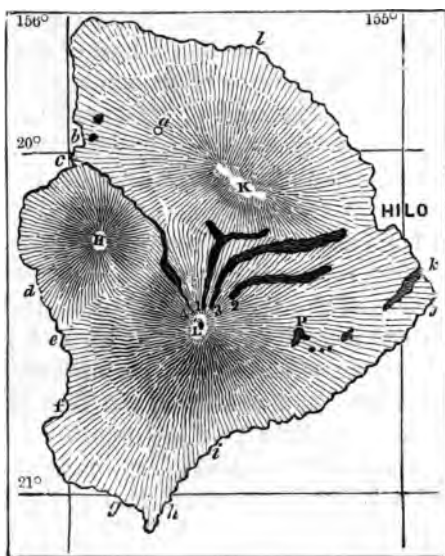
The consequence of this increase of pressure, both from the lavas and the augmented vapors, may be, and has several times been, a breaking of the sides of the mountain. One or more fractures result, and out flows the lava through the openings. Thus simple have been the eruptions.

In the eruption of 1840 the lavas first appeared at the surface a few miles below Kilauea (at P, Fig. 116), and then again at other points more remote, A, B, C, *m*; finally a stream began at *n*, a point 20 miles from the sea, which continued to the shores at Nanawale. Here, on encountering the waters, the great flood of lava was shivered into fragments, and the whole heavens were thick with an illuminated cloud of vapors and cinders, the light coming from the fiery stream below. The lavas which escaped at this relatively small eruption amounted to at least 15,400,000,000 cubic feet.

This eruption of Kilauea took place, it will be observed, *not over the sides of the crater*, but through breaks in the mountain's sides below; and the pressure of the column of lava within, and that of the escaping vapors, appear to have caused the break.

5. *Summit-crater of Mount Loa.*—Eruptions have also taken place from the summit-crater of the same mountain (Mount Loa), or at a point nearly 14,000 feet high above the sea; and in each case there has been, not an overflow from the crater, but an outflow through breaks in the sides of the mountain.

Fig. 117.



ISLAND OF HAWAII—L, Mount Loa; K, Mount Kea; H, Mount Hualalai; P, Kilauea or Lua-Pélé; 1, Eruption of 1848; 2, of 1852; 3, of 1855; 4, of 1859; a, Waimea; b, Kawaihae; c, Wainanalii; d, Kaliua; e, Kealakekua; f, Kaulanamauna; g, Kailiki; h, Waiohinu; i, Honuapo; j, Kapoho; k, Nanawale; l, Waipio; m, first appearance of eruption of 1868; n, Kahuku. The course of the currents, 1, 2, 3, and 5, are from a map by T. Coan, and 4, from one by A. F. Judd.

In 1852 there was first a small issue of lavas near the summit, and then another of great magnitude about 10,000 feet above the sea-level. At this second outbreak the lava was thrown up in a fountain, or mass of jets, two or three hundred feet high; and thus it continued in action for several days. The forms of the fountain of liquid fire were compared by

Rev. Mr. Coan to the clustered spires of a Gothic cathedral. Similar lava fountains have been observed also at other eruptions of the volcano.

The pressure producing the jet in the case above mentioned, so far as it was hydrostatic, was that of the column of lava between the point of outbreak and the level of the lavas in the summit-crater, 3,000 to 4,000 feet above. The same pressure in connection with confined vapors must have caused the breaking of the mountain in which the eruption began.

Usually, no great earthquakes accompany the Hawaiian eruptions, sometimes not even slight ones, the first announcement being merely "a light on the mountain." Moreover, when the summit-crater has been thus active, Kilauea, though 10,000 feet lower on the same mountain and even a larger pit-crater, commonly shows no agitation, no signs whatever of sympathy.

The black bands descending from the summit-crater, on the map, Fig. 117, show the courses of four great outflows of lava. The scale of the map is 38 miles to the inch.

6. Conclusions. — These cases of eruption indicate (1) that the lavas go on gradually increasing the pressure in the interior by their accumulation, while augmented activity in the production of vapors increases still further the pressure; and that finally the mountain, when it can no longer resist the forces within, somewhere breaks and lets the heavy liquid out. They show (2) that while earthquakes may attend volcanic action, they are no necessary part of it. They show (3) that lavas may be so very liquid that no cinders are formed during a great eruption; for in the ebullition of the lava in the boiling lakes of Kilauea, the jets (made by the confined vapors) are usually thrown only to a height of 30 to 100 feet; and on falling back, the material is still hot and does not become cooled fragments; it either falls back into the pool or lake, or becomes plastered to its sides. The liquidity of the lavas is shown by the jetting out sometimes, from small holes, of drops but a fourth of an inch thick, which fall back on one another, adhere, and so make a model of a little fountain.

At some of the eruptions of Mount Loa the lava has continued down the mountain to a distance of 50 or 60 miles.

2. Vesuvius.—Vesuvius is an example of another type of volcano. The lavas are so dense or viscid that jets cannot rise freely over the surface: the vapors are therefore kept confined until they form a bubble of great dimensions; and when such a bubble, or a collection of them, bursts, the fragments are sometimes thrown thousands of feet in height. The crater, at a time of eruption, is a scene of violent activity, and cannot be approached. Destructive earthquakes often attend the eruptions.

The lavas at Vesuvius may flow directly from the top of the crater; but they generally escape partly, if not entirely, through fissures in the sides of the mountain.

3. Comparison of Mount Loa and Vesuvius as to causes of eruption and nature of the mountains.—Of the two causes of eruption,—hydrostatic pressure and elastic force of confined vapors,—the latter appears to be the most effective at Vesuvius, while the former may be at Hawaii. Mount Loa, on Hawaii, is an example of the great free-flowing volcanoes of the world, and the mountain is almost wholly a lava-cone. Vesuvius is an example of a smaller vent with less liquid lavas; and the cone is made up of both solid lavas and cinders. The activity in Mount Loa appears to be kept up mainly by the fresh waters (rains) which fall over the mountain and descend through the rocks to the fires; while Vesuvius is in part, at least, supplied by salt waters from the Mediterranean, as is proved by hydrochloric acid in its vapors, and the chlorides among its saline incrustations. The waters of any subterranean streams cannot be driven back by the lavas, owing to the pressure above, and hence they must enter and be taken up by the lavas. But in all volcanoes there must be a gradual supply of lavas from below, through the action of vapors of a deep-seated source, or else the heat would sooner give out.

4. Trachytic hills.—Feldspathic lavas, such as trachyte, are

less common in modern volcanoes than the doleritic. They have in some cases preceded dolerite in the history of a volcanic cone. They are less fusible than the latter, because the feldspar orthoclase, which is the chief constituent, is a mineral of rather difficult fusibility. In some cases these feldspathic lavas have come up through fissures in so pasty a state that they have swelled up into steep *domes* and cooled in this form. Domes of this kind occur in Auvergne; also in the Black Hills (Newton and Jenny's Report).

5. Lateral cones of volcanoes. — In eruptions through fissures the lavas may continue issuing for some days or weeks through the more open or widest part of the fissure, and consequently form at this point a cone of cinders or lavas. Thus have originated innumerable cones on the slopes of Etna and other volcanic mountains.

6. Submarine eruptions. — Eruptions may sometimes take place from the submarine slopes of the mountain when it is situated near the sea, as has happened with Etna and Mount Loa; and in such cases accumulations of tufa, or of solid lavas, may form under water about the opened vent. Fishes and other marine animals are usually destroyed in great numbers by such *submarine* eruptions.

7. Subsidences of volcanic regions. — Overwhelming of cities. — Among the attendant effects of volcanoes are the sinking of regions in their vicinity that have been undermined by the outflow of the lavas; the tumbling in of the summit of a mountain; and earthquakes, or vibrations of the rocks and also of the air, in consequence of fractures. Another is the burial, not only of fields and forests, but even of cities and their inhabitants, by the outflowing streams, or by the falling cinders and accumulating tufas. Pompeii and Herculaneum are two of the cities that have been buried by Vesuvius; and every few years we hear of some new devastation of habitations or farms by this uneasy volcano. Pompeii was buried beneath tufas alone; Herculaneum lies under tufas, lava-streams of several later eruptions, and an Italian city.

19
66

C. Subordinate Volcanic Phenomena.

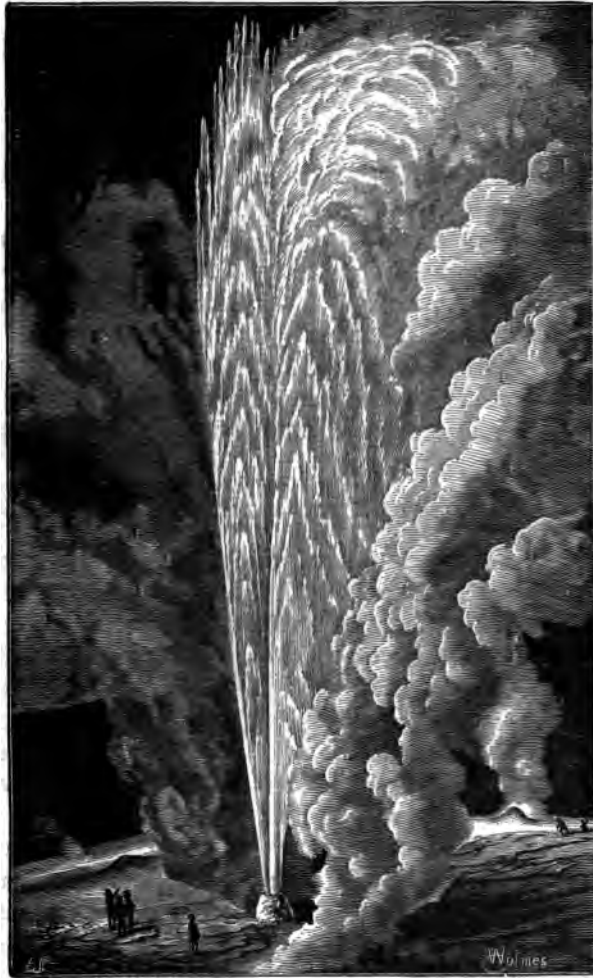
Solfataras. — In the vicinity of volcanoes, and sometimes in regions in which no volcanoes exist, there are areas where steam, sulphur vapors, and perhaps carbonic acid and other gases, are constantly escaping. Such areas are called *solfataras* (from the Italian, *solfo*, sulphur, and *terra*, earth). The sulphur gases deposit sulphur in crystals or incrustations about the *fumaroles* (as the steam-holes are called); and alum and gypsum often form from the action of sulphuric acid (another result from the sulphur gases) on the rocks.

Hot springs — Geysers. — Fountains or springs of hot waters are common in places of this kind, and are often so abundant as to be used for baths. Such springs occur also in many other parts of the world, especially in regions of upturned or of eruptive rocks. In some cases the heat is produced by chemical changes in progress beneath; but often the source is the same as for volcanic heat.

When the heated waters are thrown out in intermittent jets they are called *geysers*. The Yellowstone Park in the Rocky Mountains (between the parallels of 44° and 45° N., and the meridians of 110° and 111° W.) is the most remarkable region of geysers in the world, far exceeding that of Iceland. One of the geysers — the "Beehive" — is represented in action in Fig. 118. The action of geysers is owing (1) to the access of subterranean waters to hot rocks, producing steam, which seeks exit by conduits upward; (2) to cooler superficial waters descending those conduits to where the steam prevents farther descent, and gradually accumulating until the conduit is filled to the top; (3) to the heating of these upper waters by the steam from below to near the boiling point; when (4) the lower portion of these upper waters becomes converted into steam, and the jet of water — or the eruption — ensues. The "Beehive" jet is 200 feet high. It plays *once* a day; others play every hour.

Heated waters act on the rocks with which they are in contact and decompose them ; and as such rocks usually contain

Fig. 118.



Beehive Geyser in action.

some kind of feldspar, they become slightly alkaline through

the alkali of the feldspar, and so are enabled to take up silica and make *siliceous* solutions. The "soluble glass," used as a cement, is a sodium silicate like that of the geyser. The silica taken into solution is deposited again around the geysers in many beautiful forms, and besides makes the bowl or crater from which the waters are thrown out, and forms numerous petrifications.

When the region of a boiling pool consists of earth or mud, *mud-cones* are formed, as in some parts of the Yellowstone Park, and also at Geyser Cañon (a branch from Pluton Cañon), north of San Francisco, California.

Besides hot springs that deposit silica, there are others that deposit calcium carbonate, making thus the kind of porous limestone called *travertine*, as on Gardiner's River, Yellowstone Park.

In some cases the action of the heated waters on the rocks exposed to them gives origin to deposits of quartz crystals, agate, opal, and different silicates and other minerals.

D. Igneous Eruptions not Volcanic.

It has been stated that eruptions of volcanoes generally take place through fissures. Fissure-eruptions have also occurred in regions remote from volcanoes; and they have been the source of ejections over the western slope of the Rocky Mountains vastly greater than any from volcanic centres. Such fractures of the crust of the earth must have descended to some seat of fires or liquid rock. Whatever cause was sufficient to break through to the fire-region below would have sufficed to press out the liquid rock from beneath. The narrow mass of igneous rock which fills such fissures is called a *dike* (page 43). The liquid rock has sometimes merely filled the fracture, without overflowing; but in other cases it has spread widely over the surface, making strata of great extent and thickness. The outflow of liquid rock has often been followed by sedimentary deposits over the region, and

then another outflow has taken place; thus making alternations of fire-made and water-made strata.

The ordinary rocks of dikes are described on page 38. The igneous rock is very often without cellules or air-cavities; and, if any are present, they are in general neatly formed, instead of being ragged like those of lavas. Such a rock, having the cavities filled with minerals (as quartz, calcite, zeolites, etc.), is called an *amygdaloid*. The rock of an amygdaloid is usually *hydrous* (and chloritic) throughout (owing, it is supposed, to subterranean waters gaining access in some way while the eruption was in progress); and the cavities were formed in the outer or upper part where the diminished pressure allowed of the water's passing to the state of vapor.

Dikes are common on all the continents, especially in the regions between the summits of the border mountains and the ocean which are usually between 300 and 800 miles in breadth; as, for example, between the Appalachians and the Atlantic, and between the Rocky Mountains and the Pacific.

The Pacific slope of the Rocky Mountains (500 to 800 miles wide) is remarkable for its lava floods. Some of them are around volcanoes, or volcanic vents, but many were from fissure eruptions remote from any central source. Along Snake River (the southern fork of the Columbia), in Idaho, a single field covers 24,000 square miles, and is 275 miles in length from east to west. To the eastward there are some volcanic "buttes," and the flow appears to have been westward; but it is evident from their size that these were not the source of the widespread lavas. Of the many successive outflows, the earliest were of grayish *trachyte*, the later, of blackish *dolerite* (C. King). As usual with lavas coming from great depth through fissures (where pressure prevents vapor-expansion), no scoria occurs over the surface.

On the Upper Columbia, in Oregon, between the lofty Mt. Hood, with its fellows of the Cascade Range, and Lewiston, 250 miles to the eastward, a similar lava-field has an area of 30,000 square miles, or, with the Mt. Hood region included,

40,000. For long distances there are walls bordering the river 1,000 to 2,000 feet high, made of ranges of basaltic columns, and toward Mt. Hood, the thickness is 3,500 feet. Again, in Northern California, south of the combined volcanic area of Mt. Shasta and Lassen's Peak, on the west slope of the Sierra, the lavas of large isolated fissure-eruptions were so copious as to have obliterated the deep valleys of an old system of drainage, and forced the streams to make new channels. The erosion then begun has since cut out valleys 1,000 to 3,000 feet deep, partly along new routes, and far down into the subjacent rocks, leaving the remnants of the lava-field as caps of "Table Mountains." The miners have tunnelled beneath the lava-cap for gold-bearing gravels, and found rich deposits in the beds of the old streams. (J. D. Whitney.) Nevada, Southern Utah, Colorado, New Mexico, and Arizona have other wide lava-fields.

Still more wonderful are the fissure eruptions of the Decan, in India, where a railway out of Bombay runs for 519 miles continuously over a lava-field; its area is not less than 200,000 square miles.

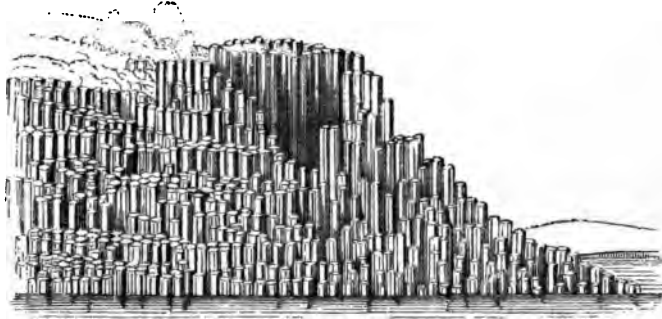
In Eastern North America, outflows through fissures made the Palisades on the Hudson; long narrow ranges through the Connecticut valley, including, among the summits, Mt. Tom and Mt. Holyoke; ridges in Nova Scotia; others similar, at intervals from New Jersey to North Carolina; and others, in the vicinity of Lake Superior. The rocks of the Salisbury Craigs near Edinburgh, and of the Giants' Causeway and Fingal's Cave, are other examples.

The lava-streams have sometimes alternated with sedimentary deposits, made largely of beds of tufa and called "ash-beds." They have in many cases *intruded between pre-existing strata*; and in this case have left effects of the heat on the *overlying* as well as the underlying bed, that is, *if moisture were present to help the heat*. Further, the intrusion of *trachytic* lava has at times *lifted* the overlying strata high enough to make subterranean dome-shaped masses 1,000 to 4,000 feet high

(named *laccoliths*, from the Greek for *lake* and *stone*); as in the Henry Mountains, Southern Utah, where denudation has exposed to view the laccoliths. (G. K. Gilbert.) Ten thousand feet of Tertiary strata are described as having been thus lifted,—evidence of the vastness of the erupting force.

The following view (from a sketch by the author, in 1840) represents a scene of columnar basalt in Illawarra, New South

Fig. 119.



Basaltic columns, coast of Illawarra, New South Wales.

Wales, another region of fissure eruptions. The verticality of the columns is proof of the near horizontality of the flow of basaltic lava.

3. Metamorphism.

1. Metamorphism. — The term *metamorphism* signifies *change* or *alteration*; and, in Geology, a *change* in the earth's rocks or strata demanding some heat, but less than for fusion, and resulting in crystallization, or, at least, firm solidification. Such changes may be either *regional* or *local*.

2. Regional Metamorphism. — In regional metamorphism, the regions undergoing change have often been thousands of square miles in area, and the depth to which the alteration has extended has sometimes exceeded 30,000 feet. The rocks were originally uncrystalline limestones, shales, sandstones,

conglomerates. They are changed to crystalline limestone or marble, mica-schist, gneiss, and the like (page 35). They were originally in horizontal strata; they are now upturned or folded, and are often intersected by veins.

New England is mostly covered by metamorphic rocks; and they spread over the eastern border of New York, to New York Island. They are the rocks of the Adirondacks and much of Canada; of the Highlands of New Jersey and Putnam County, N. Y.; of the Blue Ridge and the Black Mountains; of a large area south of Lake Superior; of high ranges along the summit of the Rocky Mountains; and of the Sierra Nevada in California. They occur also in Scotland, Wales, Cornwall, Scandinavia, and various other countries.

Proof that such crystalline rocks are metamorphic, and not igneous, is found (1) in their bedded structure answering usually to the original bedding of the strata; and (2) in the occurrence, in some portions of a metamorphic stratum, where the change is least complete, of unobliterated *fossils*: as in part of the marble of West Rutland and other places in Vermont; the limestone and schists near Poughkeepsie and elsewhere in Dutchess County, N. Y.; in the Sierra Nevada; and in several localities in Europe.

3. Effects. — The effects of metamorphism include: —

(1.) Simple compacting and solidification; as in making quartzite from sandstone, or a rock looking like granite from granitic sandstone.

(2.) A change of color; as the gray and black of common limestone to the white color, or the clouded shadings, of marble; and the brown and yellowish-brown of some sandstones colored by iron, to red, making red sandstone and jasper-rock.

(3.) In most cases, a partial or complete expulsion of water, but not in all; for serpentine, a metamorphic rock, is one eighth (or 13 per cent) water.

(4.) An evolving and expulsion of mineral oil or gas; as when *bituminous coal* is changed to *anthracite* or *graphite*.

(5.) An obliteration of all fossils; or of nearly all if the

metamorphism is partial. The obliteration is usually preceded by the compression and distortion of the fossils.

(6.) Often a change in crystallization with little or none in chemical constitution; as when a limestone is turned to white statuary marble; and a sandstone or argillaceous rock, made from the granulation of granite, gneiss, and related rocks, is changed to granite or gneiss again.

(7.) In many cases, a change of constitution; for the ingredients subjected to the metamorphic process often enter into new combinations: as when a limestone, with its impurities of clay, sand, phosphates, and fluorides, gives rise, under the action of heat, not merely to white granular limestone, but to various crystalline minerals disseminated through it, such as *mica*, *feldspar*, *scapolite*, *pyroxene*, *apatite*, *chondrodite*, etc.

It is thus seen that *metamorphism* may fill a rock with crystals of various minerals. Even the gems are among its results; for *topaz*, *sapphire*, *emerald*, and *diamond* have been produced through metamorphic action. What is of more value, it makes out of rude sandstones and limestones crystalline rocks, as granite and marble, for architectural and other uses. Man's imitations of nature are seen in his little *red bricks*.

4. Process. — *Water* and *heat* are two agencies essential in metamorphism.

Heat is important: (1) in order to produce that weakening of cohesion in and among the particles of a rock which is the preparatory step toward a recrystallization; and (2) in order to bring about the chemical changes that are required, nearly all demanding a higher than the ordinary temperature, though less than that of complete fusion.

Water is important because: (1) dry rocks (as illustrated in a fire-brick) are bad conductors of heat; (2) it helps greatly in the weakening of cohesion; (3) it takes up silica and alkali from all rocks containing feldspar (p. 142) if heated (and little heat is necessary), and thus becomes a siliceous solution, which, on cooling, may deposit the silica as a cement among

the grains of the rock and so promote its solidification—as in altering sandstone to quartzite—and may also deposit quartz in cavities or fissures; (4) at higher temperature, in the state of steam of high pressure, it decomposes readily most of the silicates or the ordinary minerals of rocks, and so prepares for the formation of new minerals—thus making sometimes *feldspar*, *mica*, *hornblende*, etc. The quartz grains of a sandstone have often had the grains converted into minute crystals of quartz by the deposition of silica over the exterior.

The *source of the water* is for the most part the rocks themselves; for beds of sandstone, limestone, etc. contain, before alteration, on an average at least 2 per cent of water (independently of any in spaces between the beds), which means 2 pints of water to 100 pounds of the rock; and since a cubic inch of water will make a cubic foot of steam at the ordinary pressure, this agent is in great quantity, and is well distributed for action.

The *source of the heat* is (1) partly mechanical; for metamorphism has generally taken place when the rocks were undergoing showings, foldings and faultings, and sometimes crushings (see page 128); and (2) partly also, that of the earth's interior heat conducted upward into the beds (page 127).

These are some of the various ways in which heated and superheated waters have aided in metamorphic changes. Direct experiments have shown that these kinds of crystallizations do result from the action of heat.

Quartz crystals, feldspars, mica, and other species have been artificially made by the subjection of the ingredients to highly heated moisture. Siliceous solutions form in waters below the boiling point; and wherever they exist they may work at consolidation, erosion, and the making of layers and veins of quartz. Large corals in Florida have been hollowed out by this means, and the cavities lined with quartz crystals or agate.

The fossils of a limestone have been silicified and flint

nodules made even *in cold waters*. The ordinary decomposition of a feldspar or mica, of hornblende or pyroxene, — one or more of which silicates occur as constituents of granite, syenite, trap, porphyry, trachyte, and of beds of tufa when first deposited, — sets free silica to make opal or quartz; and in some tufas of California and Colorado the clustered tree-trunks of a former forest, as well as scattered logs and stumps, have been petrified by silica from such a source.

Pressure is requisite for most metamorphic changes. Limestone heated without pressure loses its carbonic acid and becomes *quick-lime*; but if under pressure, as has been proved by experiment, the carbonic acid is not driven off. The needed pressure may be that of an ocean above; it may be that of the superincumbent rocks, and a few hundred feet only would suffice.

The similarity of an argillaceous sandstone to gneiss or granite is often much greater than appears to the eye. When a sandstone has been made out of a gneiss, it may have the quartz of the gneiss, and also its feldspar, in a pulverized state, along with its mica; so that the change produced in it by metamorphism might be mainly a change in state of crystallization. By simply heating a bar of steel, and cooling it slowly or rapidly, it may be made coarse or fine steel, the process changing the grains by causing the molecules of the small grains to combine, to make large ones in the coarser kind, and the reverse for the finer. There is something analogous in the change, above described, of an argillaceous sandstone to gneiss or granite. It cannot be asserted, however, that the feldspar grains in the sandstone would always remain feldspar; they may contribute to the making of mica and a mica-schist, or to that of some other mineral and rock.

Often, however, the material derived from the wear of gneiss and granite and other rocks is not only pulverized, but also more or less decomposed. The feldspar, for example, may have lost its alkalis, or the mica its oxide of iron and

alkalies, and in such a case the process of metamorphism could not, of course, restore the original rock. The new rock made would contain no feldspar or mica, if the alkalies had been wholly removed, but it might turn out an argillite or slate; or, if much oxide of iron is present, a hornblende rock, or a chlorite rock, or some other kind from which the alkalies, potash and soda, are absent.

3. Local Metamorphism.—Local metamorphism has often taken place in the walls of dikes of igneous rocks, or in the adjoining parts of the strata over or between which they have flowed, in consequence of the heat from the melted and cooling rock, and sometimes after cooling has ceased. Near dikes of trap, the rock is sometimes made cellular by escaping steam, and filled with shrinkage-fissures made on cooling or drying; and besides these effects, various minerals have been often formed, as epidote, chlorite, hematite, tourmaline, garnet, out of the ingredients present in the adjoining stratified rock, or the trap, or both,—which are true examples of metamorphic results. The waters of mineral springs, especially when they are heated, have often produced metamorphic effects in the rocks, and many mineral species have been formed by these means. Such cases of *local* metamorphism, as well as the facts stated on page 148, show that the mineral changes which take place in regional metamorphism are possible and natural results of the conditions that have existed at such times.

4. Formation of Veins.

1. Nature and origin of spaces occupied by Veins.—Some of the forms and characters of veins are shown and explained on page 42. Veins are the fillings of spaces in the rocks; and these spaces are usually (1) the cracks or fissures made by uplifting or disturbing forces; (2) by the expansion or pressure of vapors; (3) by shrinkage from cooling or drying; *they may be* (4) the openings *between the layers or laminae of*

a rock produced in the flexing of the beds, like those between the leaves of a quire of paper when folded over; or (5) open spaces made in rocks by excavation, as caverns are made.

The uplifting and flexing of rocks which have resulted in fissures and openings are often accompaniments of metamorphic change, and the fissures may have become filled before the long era of metamorphism had passed. The heat concerned in such a case may be, as explained above, that derived from the movements in the strata in connection with that of the earth's depths.

2. Materials of Veins. — *Quartz* is the most common, because siliceous solutions are easily made, they requiring little heat. *Granitic* material, requiring higher heat, is also common, but especially in veins intersecting the more crystalline rocks; and vein granite is usually much coarser in crystallization than ordinary granite. Other stony materials, less common, are *calcite*, *barite* (barium sulphate), and *fluorite* (calcium fluoride); but where these occur, quartz may also be present. Along with the earthy minerals may occur *gold*, or the various *ores of copper, lead, silver*, and other metals, besides *pyrite* (iron sulphide) which is almost universally present in ore-bearing veins or *lodes*. The earthy minerals are called the *gangue* of the ore. The ores are usually distributed in one or more planes parallel with the walls of the vein (Figs. 19, 20, p. 42), but often very irregularly; and the veins may vary greatly in size, as illustrated in Fig. 17, and have their ores only in their broader parts.

3. Origin of Dikes. — Fractures that reach down to *liquid rock* become filled by it, and thus *dikes* are formed (page 43), which are not true veins, though sometimes so called.

4. Origin of Vein Deposits. — The following are common methods: —

1. When the fissures or openings have not descended to liquid rock, and were filled from either side or below. — Vein deposits of this kind are very common. They include nearly all those consisting of quartz or granite, whether containing metallic

ores or not, and most banded mineral veins (page 42). The fissures, or openings, and part of the heat are a result of profound disturbances such as give rise also to metamorphism. The material of the vein is brought into the opening from the rock adjoining, either that directly adjoining, or that of depths below. The fissured rocks being heated, as above stated, all moisture or vapor present tends to decompose the rock-material near the fissure; it takes alkalis from the feldspars, and so becomes siliceous, and few minerals will withstand its action. The vapors press into the fissures or openings, carrying the mineral material they can dissolve, and depositing it; and they keep up supplying material until the fissure is filled or the supply of material is exhausted. It is natural that veins in gneiss and mica-schist filled in this way should often be granitic veins, for these rocks contain the quartz, feldspar, and mica of granite; or, that they should often be quartz veins simply, which they are likely to be if the temperature is not high enough to make or dissolve feldspar and mica.

Under the action, whatever metallic ores, or constituents of gems, the fissured rock contains, are carried into the fissure with the other mineral material; and additions may be received largely through vapors rising from its deeper parts.

By such means veins have been supplied with their gems and ores. The quartz veins and seams in the slate rocks of a gold region have in this way become gold-bearing veins, the gold and quartz having been brought in by the same moisture, and both having been gathered from the adjoining or underlying rocks. These openings, in the case of auriferous quartz veins, were often *openings between layers of the slate* made in the folding or upturning. Quartz veins are the usual original sources of gold; and the gold-bearing gravels, which afford the metal by simple washing, and have yielded the larger part of the gold in use, are the detritus made out of the gold-bearing rocks. The same gravels often afford platinum, *iridium*, and diamonds.

While fissures filled by this lateral inflow of material, in connection with emanations from the depths below, may be *uniform* in material across, as in many quartz veins or seams, they may also consist of bands of different minerals, like many metallic veins (page 42). In the formation of banded veins the process has brought in for a while one kind of mineral, as quartz, and deposited it over the walls of the fissure; then, through some change, some other mineral or ore, as an *ore of lead*, or one of *zinc*, or one of *copper*; then *quartz* again, or *fluorite*, or *calcite*; and so on until the fissure was filled.

The above is one of the methods by which the earth's precious metals have been gathered out of the rocks, in which they were sparingly disseminated, into generous veins, and thereby placed within reach of the miner.

2. Where the fissures have descended to regions of liquid rock and were filled from below. — (a) Dikes of porphyry, dolerite, and related rocks are sometimes the courses of veins of metallic ores. The veins are generally situated near the walls of the dike, and either in the igneous rock or in the rock adjoining.

The veins may have been made (1) when the dike was made, or (2) they occupy fissures made subsequently, but during the same epoch of disturbance, or (3) they have been formed later, the old plane of fracture being a plane of weakness liable to be opened anew. The metallic materials of the vein have been brought up as solutions or vapors, either from the depths that afforded the igneous rock itself, or, more probably, from the walls of a deep part of the fissure.

The veins of native copper at Keweenaw Point, those of the same metal with ores of copper in the Red sandstone (Triassic-Jurassic) of the Connecticut Valley, New Jersey, and Pennsylvania, those of silver ores in Nevada and other mines along the Rocky Mountains and Andes, thus originated, — that is, in connection with igneous ejections; the ores not coming up as a constituent part of the igneous rock, but

mainly through the aid of vapors, and often those of subterranean waters.

(b) Frequently in regions of igneous ejections fissures have been made that have received not igneous rock, but only vapors or mineral solutions from below, and thus have become metallic veins. Each of the regions just mentioned contains examples of such veins.

The filling may continue in progress long after the igneous rock is cooled, or as long as heated vapors continue to rise through the fissure. Shrinkage-cracks and openings made by vapors in the rock adjoining the fissure may spread the mineral depositions widely on either side. The vent may continue as a source of heat to surface waters, making hot mineral springs and steaming pools or basins, about or from which depositions may take place of a vein-like character, as is going on now in Nevada and California.

At Leadville, in Colorado, the ores of silver and lead occur in veins and deposits beneath a stream or bed of igneous rock; and they probably came up from depths below through the fissures which were opened at the time of eruption, but which may have long given passage to hot vapors. The original material in the depths below may have been chiefly a silver-bearing galenite (lead sulphide); but through the heat and vapors from those depths, and ingredients met with above, they are now different ores of silver, along with silver-bearing galenite, mixed with lead carbonate, lead sulphate, iron oxide, and other minerals, and much disguised by the mixture. They occur mostly in connection with a limestone that was greatly eroded in the process.

3. Fissures or cavities filled by infiltration or deposition from above. — Wide cracks opening to the surface have sometimes been filled with sand or earth, producing a kind of vein or dike. Small cracks through rocks, shrinkage-cracks, and others have often been filled with calcite by infiltration from above, and sometimes by other minerals held in solution by infiltrating waters.

Depositions of galenite or lead ore (with sometimes nickel and zinc ores) have taken place in cavities or caverns in limestones, as in Wisconsin, Illinois, and Missouri, and Cumberland and Derbyshire, England. The ore is often supposed to be in veins, when, actually in local deposits that were made by supplies from above. Yet they often have great extent, and are a valuable source of ore, as in the American localities mentioned (as first deduced by J. D. Whitney), and probably in many others. The condition of the ore-beds shows that when the deposition was in progress, the limestone underwent much erosion from acid solutions concerned in or resulting from the changes.

Many cases of extensive bodies of ore in cavities in limestone appear not to be of the above-mentioned kind, but to be properly vein deposits. They may in some cases have originated in fissures which produced ore-deposits only where they intersected limestones, because only limestones were easily rendered cavernous by the eroding vapors so as to afford spaces for the ores.

5. So-called veins that are not true veins. — In the course of the earth's rock-making, metallic ores have often been deposited along with the detritus when a sedimentary bed was in progress of formation; they have been brought into marshes, or spread over confined sea-margins and mud-flats, by running waters which took up the metal (in some soluble state of combination) from the decomposing rocks of the region around. Deposits of iron ores are thus made at the present time (page 85), and those also of zinc, cobalt, nickel, and copper were so made in early geological ages. When strata containing such metalliferous layers have undergone uplifts and crystallization, the nearly vertical beds *look like veins*. The great deposits in the Archæan terranes of hematite and magnetite are beds, not veins or dikes.

V.—MOVEMENTS IN THE EARTH'S CRUST: THEIR CAUSES AND CONSEQUENCES.

As a preparation for the study of the following pages, it is important that the subject of flexures, fractures, and displacements, explained on pages 52–56, should be well understood, and also that the facts, on pages 217 and 276–281, connected with the making of the Green Mountains and Appalachians should have been previously perused.

1. Explanations already given.—In the preceding chapters the origin of many geological phenomena, and of some of the earth's features, have been briefly explained.

A. Changes of level have been described as caused (1) by change of temperature, this cause producing the expansion and contraction of rocks (p. 128); (2) by undermining due to subterranean water (p. 102); (3) by undermining due to volcanic outflows (p. 139).

B. Mountain forms have been described as often a result of the sculpturing of elevated plateaus of nearly horizontal rock by streams, as exemplified among some of the most majestic mountains of the globe (p. 95).

C. Folding of beds has been shown to have been caused when they are clayey, soft, and wet, by a lateral movement produced through the pressure of superincumbent material (p. 106).

D. Fractures and faultings of strata have been attributed (1) to undermining by different methods (pp. 102, 139); (2) to contraction or expansion; (3) to shrinkage on drying, producing deep or shallow fractures (p. 129); (4) to the expansive force of vapors (p. 135); (5) to the hydrostatic pressure of a column of lava (p. 135); and to other causes.

E. Lamination parallel to the bedding, as in the shaly structure, has been explained as a possible result of the pressure to which wet argillaceous beds have been subjected through *the weight of overlying strata.*

F. Metamorphism has been described as produced on a small scale, (1) in the vicinity of dikes of igneous rock, through the heat of the rock when it was cooling from fusion, if vapors or moisture were present to aid; and (2) also in the neighborhood of hot springs (p. 150).

G. Earthquakes have been stated to result from fractures of rocks in subterranean regions, consequent (1) on undermining (p. 102); or (2) on movements and fractures attending volcanic action (p. 139).

But none of the causes that have been considered explain the great changes of level involving large parts of continents or of oceanic areas; or the phenomena attending the making and uplifting of mountains; or the widespread or regional metamorphism that has turned simultaneously sedimentary beds over thousands of square miles into crystalline rocks; or the earthquakes that have shaken a hemisphere.

2. Relation in size between the earth and its mountains.— On a globe twelve feet in diameter, the height of the earth's loftiest mountains would be represented by an elevation of about one twelfth of an inch; the whole difference of level between the deepest part of the oceanic basin and the highest point of the land, by twice this amount; and the mean depth of the ocean, by a depression of one twentieth of an inch. The deformation of the sphere produced in the making of the continents and mountains was, therefore, very small.

3. Facts as to changes in level that are explained by a change in water-level.— The subject of the origin of changes of level is complicated by the fact that the base from which such changes are measured is the water-plane of the ocean, and this is far from constant, especially in the vicinity of the continents.

(1.) The deepening of any part of the oceanic basin would produce *apparent* elevation of the land; and the thousand feet of mean elevation of the land above the ocean has been attributed to this cause.

(2.) The lifting of mountains on a continent, or the piling

of ice to mountain heights (as in a Glacial era), makes the pendulum move some seconds of arc toward the high region, and alters correspondingly the *level* of the adjoining ocean, and thus draws the waters over the land, diminishing the actual height of the mountains above the sea; even a thousand feet of height in the land causing a displacement in the pendulum and level, as has been found in different regions, of five or six seconds.

(3.) The accumulation of ice of great thickness about either pole would change the level of the ocean from the pole to the equator, and in proportion, approximately, to the sine of the latitude; it would cause a like displacement in the pendulum and level, and hence diminish the slope southward of the land of a continent, besides submerging to some extent the coast regions. The same result would follow from an increase in the solid material of the arctic area through detritus from northward-flowing rivers. But there would be no effect in either case provided the crust beneath subsided to an equivalent amount.

(4.) A gradual retardation of the earth's rotation (such as tidal friction tends to occasion) would diminish centrifugal action, and hence should lead to a diminution in the depth of equatorial waters (involving an emergence of tropical land), and to an increase in that of the polar, provided a sinking of the tropical crust does not take place as a consequence of the change. The fact that the great mountain chain of Western America is *lowest* in a portion of its tropical part is the opposite of that which the retardation alone should produce.

4. Facts as to changes in level that are not explained by changes in water-level or the earth's attraction. — Some of the above causes have produced effects which the geologist has to study out. But the grander changes of level are not thus explained; and if not the grander, then not the larger part of the smaller. The raising of mountain ranges, with the accompanying upturning or flexing, faulting and metamorphism of strata, have some other explanation. The lifting of a marine

formation — as the Cretaceous, with the crust it rests on — ten thousand feet higher in the Rocky Mountains than on the Atlantic border, is an example of a large class of facts to be explained by some different method; and so is the lifting of the same beds along the whole length of the mountains from Central America to the Arctic, but with maximum effect within the area of the United States. The subsidence of great areas, in some cases 10,000 to 40,000 feet, — the maximum exceeding the maximum depth of the ocean, — during the accumulation of beds for mountain-making, is another effect of some different cause; and so are probably very many of the gentle oscillations of level which have attended the deposition of the successive strata of a formation, as those of the Carboniferous age.

5. Bearing of facts as to the direction of action of the mountain-making force. — The characteristics of the force at work in mountain-making are to be largely learned from the results produced. The following are some of these results: —

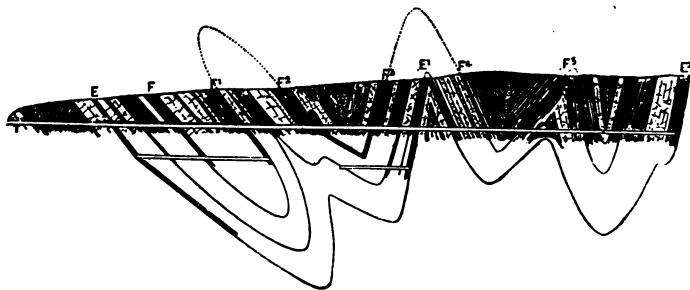
(1) It has placed the mountains mostly along the borders of the continents; (2) it has made the highest mountains on the borders of the largest oceans; (3) it has pressed up strata many thousands of feet in thickness into great folds, some exceeding 10,000 feet in height, and forced fold against fold, in succession, over breadths of one or more hundred miles, and along belts a thousand and more miles in length; (4) it has made more numerous and much steeper flexures, and more metamorphism and igneous eruptions, on one side of a mountain range than on the other, so that a mountain range is a one-sided structure; (5) it has often made the larger part of the flexures correspondingly one-sided; that is, with one slope steeper than the other.

The points here enumerated are well illustrated on the pages already referred to. Unequal-sided flexures are represented in the sections from Pennsylvania and Virginia on page 279; and in the figures (by Prof. Lesley) on page 97, which, although ideal, present actual facts from the up-

turned rocks of Pennsylvania. The ideal section on page 55 (Fig. 47) exemplifies the common fact as to crowded, steep reversed folds on one or the other side of a mountain area of steeply flexed rocks: as is well illustrated in the Appalachian chain from Alabama to New England and beyond.

The following figure represents a vertical section of the anthracite region between Neshquehoning Valley (on the west, left in section,) and Mauch Chunk. (From the Report

Fig. 120.



Section of the Panther Creek Anthracite basin at Nesquehoning tunnel (r).

of C. A. Ashburner of the Geological Survey of Pennsylvania under Prof. Lesley.) The length is about 1,200 yards (the scale of the figure being 1,000 feet to the inch). The flexures to the west have their summits pushed westward 40° beyond the vertical. The folded rocks consist of beds of anthracite and intervening strata of shale and sandstone; and the anthracite beds include the great "Mammoth bed" (lettered at its outcrop E, E¹, E²) which is 13 to 27 feet thick, and the bed F (outcropping at F¹, F², F³, F⁴, F⁵) 11 to 20 feet thick, besides one of 8 to 9 feet. The "Mammoth bed," is doubled on itself at E¹.

The facts thus far published sustain the conclusion that the mountain ranges of the Appalachian chain, and the most of the flexures of the included strata, are inequilateral. The Rocky mountain region exhibits this feature in having

several great, nearly parallel, mountain ranges between its summit and the Pacific — among them, the Wahsatch Mountains, the Humboldt ranges, the Sierra Nevada and Cascade Range, and the Coast Range — and almost nothing to correspond on the eastern ; in having its areas of igneous rocks confined almost wholly to the western slopes, with its greatest line of volcanoes not far from the ocean's border ; and in having metamorphic rocks widely distributed on the western side, and sparingly on the eastern.

Thus it is proved that the force has in general acted laterally, that is, from one side, as the pushing side, and that it was, therefore, lateral pressure, however it may have been occasioned. It is to be noted that it has produced its greatest effects along the borders of the continents over an area one to eight hundred miles wide. It has made long ranges, by simultaneous action, along the course of the progressing uplift, and has acted from nearly the same direction in all the upliftings of any region from Archæan time to the present.

6. Bearing of known facts on the question as to the earth's interior condition. — From the great subsidences, — like that of 30,000 feet or more, which was a prelude to the making of the Appalachians, — it may be inferred *that plastic rock exists beneath*, to be pushed aside so as to render subsidence possible. The great elevations have been explained only upon the assumption of a flexible crust overlying something plastic.

The earth is believed to have slowly cooled from a state of liquidity. It is urged by many physicists, though not by all, that it has become solid *throughout*, as solid as steel or glass ; the conclusion being based on the ground that if liquid within, the crust would yield with the earth's rotation, and hence the precession of the equinoxes and the tides of the ocean would be different in amount from what they actually are. It seems to be evident that geological facts cannot be explained on the basis of absolute solidity. There must have been in past time, as many have urged, either a plastic layer between the

crust and a solid nucleus, or, at least, the remains of such a plastic layer, wherever the great movements have taken place.

But it is stated that if a plastic layer exists, and the crust above it is thin, — say twenty-five miles, — the crust would rest on the mobile sea underneath it like a floating mass, the earth's surface being so nearly flat, and hence it would be pressed down by any local addition to its weight, however slight; that it could not sustain mountain elevations, except the lower part of the crust beneath the mountain were flexed downward as the upper part was forced upward, so as to leave a vacant space between, and thus make a float for the mountain to stand on; and it is held by some to be mathematically demonstrated that a protuberance of the lower part of the crust must necessarily accompany any elevation of the upper part (Rev. O. Fisher). It has been proved also that, in the case of a crust of the small thickness stated, the force from contraction and the gravity of the crust would be great enough to produce all the inequalities of the earth's surface; but the same author reaches the conclusion that only a small part of the actual inequalities could have resulted from its action.

It seems to be evident that, with a crust so mobile as above described, the lateral pressure generated within it could have produced no long range of mountains, under one common method of action; nothing of that uniformity of results exhibited in many great regions from Archæan time onward; no mountain borders for the continents; no general system of feature lines for the globe.

The facts would appear, therefore, to prove that the crust must exceed twenty-five miles in thickness; must be thick enough to have in some degree the virtues of an arch, and yet not so thick that flexures and displacements, under the conditions existing, were impossible. The demands of physical science as to a solid globe may perhaps be met by assuming that whatever the condition of the plastic layer underneath

the crust in past time, only the remains of it now exist, the part of it beneath the oceans and the interiors of continents having largely disappeared by solidification.

1. Evolution of the Earth's Fundamental Features.

Although it is not proved that lateral pressure or thrust in the crust, resulting from slow cooling, was actually the chief source of the movements in mountain-making, no other theory of mountain-making has been substituted by those who reject it. Having, consequently, no new theory to present, that based on contraction from cooling is here explained.

The following have been set forth as the different steps in the evolution of the earth's features. They correspond with the fact that all changes in the progressing earth went forward under a simple, comprehensive method of development.

1. The Mountain-borders of the Continents, highest and most abounding in volcanoes on the sides of the largest Ocean.—The oceanic area, besides being much depressed below the continental, has rather abrupt sides to the true oceanic basin, as explained on page 12. The lateral pressure in the crust being universal over the sphere, the force in the oceanic crust would hence have acted obliquely upward against the crust of the continental border. The action was that of a shove or thrust from the direction of the ocean, and in each oceanic area was somewhat proportional to its extent; consequently, bendings, uplifts, fractures, foldings of strata, earthquakes, mountain-making, became eminently features of the continental borders, and most prominently so of the borders which faced the largest oceans.

2. Method of action, and its progress in North America.—The two systems of forces engaged in the progress of North America were those from the direction of the Atlantic and the Pacific basins—the latter the greatest. Under their action the V-shaped Archæan dry land (map, page 199) was

first defined, one branch stretching northeastward to Labrador and the other northwestward to the arctic seas, and thus facing respectively the Atlantic and Pacific areas, while mountains were made along the course of the Appalachian chain and the Blue and Highland ridges. It follows, from the courses of the arms of the **V**, and of the mountains, that the Atlantic force acted mainly from the southeastward, and the Pacific from the southwestward, and the two, therefore, nearly at right angles to one another. It is also apparent that the Pacific force even then was the greater, and hence the Pacific Ocean the larger; for the northwestward branch of the **V** is far the longer.

Thus the Archæan nucleus was outlined, and the position of Hudson's Bay determined within the arms of the **V**. From this nucleal dry land progress went forward southeastward, or toward the Atlantic, and southwestward, or toward the Pacific, successive formations being added under gentle oscillations, and the dry land gradually extending under changes of level caused mainly by the same forces. Then, when the Lower Silurian closed, appeared the Green Mountains; and when Paleozoic time was closing, appeared the Alleghany part of the Appalachian chain, parallel to the *eastern* branch of the Archæan heights. Later still rose the trap ridges of the Mesozoic on the Atlantic border (p. 286), making another parallel to the eastern branch, or tripling the arm of the **V** on the east, and even repeating all the bends in the Appalachians.

Again, on the Pacific side, other ranges were made, parallel to the course of the Rocky Mountain chain; among them — after the Jurassic period, the Sierra Nevada, and, after the Cretaceous, the Wahsatch, and still later, Tertiary ridges toward the coast, each epoch adding new parallels to the western branch of the Archæan nucleus. Finally, in the course of the Tertiary, the mass of the Rocky Mountains rose to its full height above the ocean.

Each added range, as is seen, proves that the mountain-

making forces continued to act to a large degree from the same directions as in Archæan time.

Thus, the continent made progress, adding layer after layer to the rocks over its surface, and range after range in parallel lines to its heights, until finally the continental area reached its limit, and the great interior basin had its mountain-borders completed: on the *east*, the low Appalachians, and the trap ridges of the Mesozoic; on the *west*, the massive and lofty Rocky Mountain chain, with the parallel ranges over its western slopes.

It is explained beyond (on page 373) that, when the continent was thus far completed, there occurred a change in the region of progress. The high-latitude operations of the Quaternary then began.

On this view, the evolution of the features of the surface went forward through one system of forces originating in one single cause, — the earth's contraction from cooling. North America, which is here appealed to for explanations, affords the truest and clearest illustration of the principles involved in the system of evolution, because it lies alone between the two oceans, the Atlantic and Pacific, with the nearest continent, South America, to the east of its meridians. The progress on this account went forward with great regularity, each age repeating the preceding in the direction of all oscillations or uplifts. It was a single isolated individual making systematic progress throughout until its final completion, and exhibits truly the system in the earth's development, whatever the true theory of that development. Europe, in contrast, has Africa on the south and Asia on the east; it is, therefore, full of complexities in its feature lines, and in the succession of events that make up its geological history.

2. Formation of Mountain Chains.

1. **A Geosyncline, or downward bend of the Crust, the first step in ordinary Mountain-making.** — In the making of the

Appalachians there was first a slowly progressing *subsidence*; it began in, or before, the Cambrian or Primordial period, and continued in progress until the Carboniferous age closed. As the trough deepened, deposits of sediment, and sometimes of limestone, were made, that kept the surface of the region near the water level; and, when the trough reached its maximum, there were at least 30,000 feet in thickness of stratified rock in it (page 277), and this, therefore, was the depth of the trough. The Green Mountains began in a similar subsidence, and at the same time; and the trough was kept full with deposits as it progressed; but it reached its maximum, or the era of catastrophe, at the close of the Lower Silurian. Such facts are in the history of many, if not all, mountains.

2. The bottom of the Geosyncline weakened by the Heat rising into it from below.—As planes of equal temperature within the earth have a nearly uniform distance from the surface, the accumulation of sedimentary beds in a sinking trough would occasion, as Herschel long since urged, the corresponding rising of heat from below, so that, with 30,000 feet of such accumulations, a given isothermal plane would have been raised 30,000 feet. Under such an accession of heat, the bottom of the trough would have been greatly weakened, if not partly melted off. If the lower surface of the crust had dipped down this much into the plastic material that was beneath it, it would have been actually melted off. The lateral pressure, acting against a trough thus weakened, would end, as has been suggested, in causing a collapse, that is, a catastrophic break of the trough below, and a pressing together of the stratified beds within it. And with this break the shaping of the mountain would begin.

3. Character of the Mountain thus made.—Under such circumstances the stratified rocks lying in the geosyncline or trough would be folded, profoundly broken, shoved along fractures, and pressed into a narrower space than they occupied before. The crust beneath was that of the geosyncline; and lateral pressure, however powerful, could not possibly

have given an upward bend at the time to the downward flexed crust. The flexures *were flexures in the overlying strata*; they were too small to have been made also in the thick crust on which the strata lay (p. 160). They became unequal-sided, as represented on page 279, and the mountain itself inequilateral (p. 159), because there was a pushing side in the mountain-making, the force coming mainly from one direction (the oceanic, in the case of the Appalachians). Faults of 10,000 to 20,000 feet were among the effects, because the crust was under the vast pressure, and could break in oblique planes, where it could not bend; and because after breaking, it would continue to yield and thus be shoved up or down along the plane of fracture. Such a mountain range, begun in a geosyncline and ending in a catastrophe of displacement and upturning, has been named a *synclinore*, it owing its origin to the progress of a geosyncline. (The word is from the Greek for syncline, and *ōpos*, *mountain*.)

On the side away from the chief source of movement, and beyond the profoundest faults, the elevations that have taken place have commonly made vast plateaus of nearly horizontal beds, like the Cumberland mountain region of Tennessee and its continuation through western and northern Pennsylvania, to the Catskill Mountain plateau of southern New York, on the outskirts of the Appalachian range; and the Uintah Mountain plateau and others of southern Utah, on the outskirts of the Wahsatch range. In such elevated areas, several thousands of feet above the sea level, and of wide extent, running waters have had their opportunity for sculpturing, and have thus made some of the most majestic mountain groups of ridges and peaks in the world. In Tennessee, the region of great folds and faults directly east of the Cumberland plateau was at first, beyond doubt, of far greater height than the plateau; but owing to the vast amount of fracturing as well as the steep slopes, denudation has finally made it lower, and it is now the "Valley of East Tennessee,"

while the plateau is "Cumberland Mountain." Not less was the denudation in front of the Catskill plateau.

4. A Mountain Chain may comprise ranges of different epochs of origin. — The Appalachian chain consists of (1) mountains of Archæan age; (2) the Green Mountains, that date from the close of the Lower Silurian; and (3) the Alleghanies, that were formed at the close of the Carboniferous age. The Green Mountains began in the same great geosyncline with the Alleghanies; but that part reached its completion first, probably because so near the stable Adirondack border of the continent. It is probable that the Archæan portion of the Appalachian chain — which includes the Blue Ridge, the New Jersey Highlands, continued in Putnam County, N. Y., some areas in western New England, and the Adirondacks, — corresponds to another older synclinore. Thus a mountain chain may comprise several ranges, made at widely different epochs.

5. Metamorphism and other attendant effects. — The heat developed through the transformation of motion, added to that rising into the strata from below, would produce all the consolidation and crystallization — that is, all the metamorphism — which has been in any case observed, and on a scale as vast as that of the mountain range so developed. It gives a full explanation, therefore, of the origin of regional metamorphism.

The heat might be sufficient in some parts to reduce a rock to a plastic state, and so obliterate all its original bedding. One result of this would be to make a massive metamorphic rock, like granite, in place of gneiss or other schistose kind; and another result, if the overlying rocks were fractured, and so fissures opened down to the plastic rock, would be to fill the fissures with the plastic rock, making dike-like veins of granite, or of other material, according to the kind of rock so fused. It might possibly give a long core, or central mass, of granite to a mountain-range, — a condition of the Sierra Nevada which has been attributed by some to this cause.

6. Slaty cleavage, jointed structure. — *Slaty cleavage* has been proved by experiments to result whenever fine-grained rock-material is subjected to pressure; and to be due to the flattening of all air-cells and compressible particles, and the arranging of all flat grains in planes at right angles to the pressure. As it occurs in upturned or flexed rocks of fine grain, the pressure producing upturning or flexure, and also mountain-making, has been generally the cause. It conforms to the bedding whenever the bedding is, as a consequence of the upturning, at right angles, or nearly so, to the pressure.

A *jointed structure*, on the large scale observed in many regions, has been another result of the slow uplifting or flexing action from lateral pressure. The strain, after accumulating through a long period, has ended in fractures of great depth, evenness, and general parallelism, at right angles to the direction of the pressure, and often also in a subordinate system of fractures transverse to it; sometimes also — when a warping of the beds was likewise in progress — in joints that were not parallel. Slowly accumulating pressure from any other source would produce like results.

In many quartzose sandstones the grains are so loosely coherent that the vibrations attending any upturning and fracturing tend to shake out all traces of the original bedding. At the same time, the lateral pressure produces planes of apparent bedding and division at right angles to its direction, — partly as a result of the strain attending the movements, and partly owing directly to the pressure, as in slaty cleavage. Hence quartzites, which are metamorphic sandstones, seldom retain their true bedding, but have nearly vertical divisional planes instead.

7. Geanticlines in Mountain-making. — In the movements of the earth's crust, there would necessarily be *upward* as well as downward flexures, — that is, *geanticlines* as well as *geosynclines*. The Appalachians, as explained above, may, when first made, have stood up in ridges, without having undergone any uplifting from an elevation of the crust underneath.

But, however this may be, the region actually experienced elevation before the Triassic period opened, as is proved by the position of the Triassic beds; and this took place probably through a gentle upward bending of the crust, such a bending becoming possible after (although not before) the region of the Appalachians had been made a portion of the stable part of the continent.

The Rocky Mountains, in the Cretaceous era, within the area of the United States, were 10,000 feet below their present level, the sea covering them (p. 323). They were raised as a whole during the Tertiary, and it must have been through a low geanticline. While the Tertiary mountains were in progress, the part of the force not expended in producing them appears to have carried forward an upward bend, or geanticline, of the vast Rocky Mountain region as a whole.

After the crust had become thickened by the earth's internal cooling, through the ages, and had been stiffened also by the plication and solidification, and partly the crystallization, of the strata, geosynclinal troughs over the continents, like that of the Appalachian region, became less a possibility; and consequently the chief movement caused by the ever-continuing lateral pressure would have been an upward one. It may be for this reason that the mountain-chains received their great height so largely in the Tertiary; and that the areas over the earth's surface that were affected by single movements, such as the high-latitude movements of the Quaternary, were so vast. There was, also, in the Quaternary, if Darwin's view as to the formation of coral atolls (that presented on page 78) is right,¹ a *downward* bending through the warm parts of the

¹ Darwin's theory explains completely the observed facts with regard to coral formations. But it assumes the fact of a great oceanic subsidence, which has not been independently proved. It has been suggested that shells of Rhizopods and the stony secretions of other forms of marine life may have built up portions of the sea-bottom to within 100 or 120 feet of the surface — the depth at which reef-corals can grow — and that only the upper 120 feet consist of coral-reef rock; and, in order to account for the open interior,

oceans, — the coral island subsidence, — affecting an area in the Pacific over 5,000 miles in its longer diameter; an extent far beyond that of the mountain-making geosynclines of earlier time. It may be that the Pacific coral-island subsidence was the counterpart of the geanticlinal movement over the continents of the later Tertiary and early Quaternary.

8. Fractures and outflows of igneous rocks most numerous in later geological times. — Great floods of doleryte and trachyte were poured out over the Rocky Mountain slope, after the close of the Cretaceous period. The previous plications and solidifications of the strata involved in the making of the various ranges of mountains would have left the crust firm and unyielding; and, being too stiff to bend, it broke, and hence the eruptions. It had broken at times before; but at this time the fractures became much more numerous, and the floods of rock more extensive. Moreover, from this era appears to date the opening of the great volcanoes of the Cascade range. In fact, the larger part of the volcanic eruptions of the world are probably, for a like reason, of Tertiary and later origin.

Such are the general steps of progress, and their explanations, according to that theory of mountain-making which attributes the movement to a lateral thrust in the earth's crust

or lagoon, of the coral island, it is further supposed that the structures were begun on the rims of submarine craters.

The objections to this theory are: (1) that the existence of craters in the lava accumulations made by *submarine* volcanic action is improbable; (2) that no craters of known volcanoes have even approximately the size of many of the lagoons of atolls; (3) that the lagoons are never circular, but as irregular in outline, nearly, as the other islands of the ocean; (4) that in the Feejee group all the steps in the progress of an atoll assumed in the Darwinian theory are exemplified, from the high volcanic island with a fringing reef, to the atoll, 15 miles in diameter, having two small peaks of volcanic rocks in the great lagoon. (See map of the Feejee group in the author's "Corals and Coral Islands," 378 pp. 8vo, New York.) A few borings in a coral island to a depth of 500 or 1,000 feet, with a drill large enough to give a core six inches in diameter for examination, would settle the question as to whether the rock below is of coral-reef origin or not.

as a result of contraction on cooling. The universality of system in the features of continents and the characters of mountains has as yet no other probable explanation. Speculation has appealed to the power of crystallization as a determining cause for at least the direction of the grand feature lines. But of this there is too much uncertainty for any confidence in the view.

To obtain an adequate idea of the slow progress of the earth in the making of its mountains, it is necessary to remember that the process has gone on only after immensely long periods of quiet and gentle oscillations. After the beginning of the Cambrian, the first period of disturbance in North America of special note was that at the close of the Lower Silurian, in which the Green Mountains were finished; and *if* time, from the beginning of the Silurian to the present, included only 48 millions of years, (p. 375) the interval between the beginning of the Cambrian and the uplifts and metamorphism of the Green Mountains was at least 20 millions of years. Another epoch of disturbance was that at the close of the Carboniferous era, in which the rocks of the Alleghanies were folded up; on the above estimate of the length of time, it occurred about thirty-six millions of years after the commencement of the Silurian; so that the Alleghanies were at least 36 millions of years in making, the preparatory subsidence having begun as early as the beginning of the Silurian. The next on the Atlantic border was that of the displacements of the Triassic-Jurassic sandstone and the accompanying igneous ejections, which occurred before the Cretaceous era, — at least five millions of years, on the above estimate of the length of time, after the Appalachian revolution. Thus, whatever the mountain-making force, an exceedingly long time was required in order to accumulate a sufficient amount to produce a general yielding and plication or displacement of the beds, and start off a new range of prominent elevations over the earth's crust.

REVIEW OF THE ANIMAL AND VEGETABLE KINGDOMS.

THE following pages on the Animal and Vegetable Kingdoms are inserted in this place to prepare the student for the following portion of the work, on Historical Geology, in which the *progress of life* is a prominent part.

Distinctions between an Animal and a Plant.

1. **An Animal.** — An animal is a living being, sustained by nutriment taken into an internal cavity or *stomach*, through an opening called the *mouth*. It is capable of perceiving the existence of other objects, through one or more senses. It has (except in some of the lowest species) a head, which is the chief seat of the power of voluntary motion, and which contains the mouth. It is fundamentally a *fore-and-aft* structure, the head being the anterior extremity, and it is typically forward-moving. With its growth from the germ, there is an increase in mechanical power until the adult size is reached. In the processes of respiration and growth, it gives out carbonic acid and uses oxygen.

2. **A Plant.** — A plant is a living being sustained by nutriment taken up externally by leaves and roots. It is incapable of perception, having no senses. It has no head, no power of voluntary motion, no mouth. It is fundamentally an *up-and-down* structure, and, with few exceptions, *fixed*. In its growth from the germ or seed, there is no increasing mechanical power. In the process of growth, it gives out oxygen and uses carbonic acid.

I. Animal Kingdom.

1. The Animal Structure.

The nature of an animal requires, for a full exhibition of its powers, the following parts :—

1. A stomach and its appendages to turn the food into blood, with an arrangement for carrying off refuse material.

2. A system of vessels for carrying this blood throughout the body, so as to promote growth and a renewal of the structure.

3. A heart, or forcing-pump, to send the blood through the vessels.

4. A means of respiration, or of taking air into the system (as by lungs or gills), because this growth and renewal require the oxygen of the air to act in conjunction with the blood, as much as a fire requires air in order that the fuel may burn.

5. Muscles, or contractile fibres, to act by contraction and relaxation in putting the parts or members in motion.

6. A brain, or head-mass of nervous matter, and a system of nerves, branching through the body, to serve as a seat for the will and for the power of sensation and motion, and to convey the determinations of the will and sensation through the body.

In the lowest form of animal life, as some microscopic Protozoans, the stomach is not a permanent cavity, but is formed in the mass of the tissue whenever a particle of food comes in contact with the body. In other words, a stomach is extemporized as it is needed. In species of a little higher grade, as Polyps, there is a mouth and stomach, with muscles, an imperfect system of nerves when any, and a means of respiration through the general surface of the body; but there is no distinct heart, and the animal is ordinarily fixed to a support.

2. Subdivisions of the Animal Kingdom.

Animals (with the exception of some inferior species formerly referred to the Articulates and of little geological importance) have been divided into five groups, called *subkingdoms*. These five sub-kingdoms are the following:—

1. *The Vertebrate*: having (as in Man, Quadrupeds, Birds, Reptiles, and Fishes) an internal jointed skeleton, of which the backbone is called the *vertebral column*, and each of its joints a *vertebra*; and a bone-sheathed cavity along the back for the great nervous chord.

The remaining sub-kingdoms have *no vertebral skeleton* and are called *Invertebrates*.

2. *The Articulate*: having (as in Insects, Spiders, Crabs, Lobsters, Worms) the body and its appendages (as the legs, etc.) articulated, that is, made up of a series of joints.

3. *The Molluscan*: having (as in the Oyster, Clam, Snail, Cuttle-fish) a soft, fleshy body without articulations or joints, and without a radiated structure; and the appendages, when any exist, also without joints. The name is from the Latin *mollis*, *soft*.

4. *The Radiate*: having (as in the Polyp, Medusa, Sea-urchin, Star-fish) the body, both externally and internally, radiate in arrangement, that is, having similar parts or organs repeated around a vertical axis,—as in a flower the parts are radiately arranged about its centre or central axis.

Those Radiates which have the mouth the only opening to the digestive cavity are called *Cœlenterates*, from the Greek for *hollow within*. They include all Polyps, together with the Medusæ and other Acalephs (p. 184).

5. *The Protozoan*.—Besides the above, there are other species of so extreme simplicity that neither of the systems of structure above mentioned is apparent in them, and these are, therefore, in a sense *systemless* animals. Many have not even a mouth. They include the Sponges, and also a large number of minute species, visible only with the aid of a microscope.

1. Sub-kingdom of Vertebrates.

Class 1. — Mammals. — Warm-blooded animals that suckle their young, as Man, Quadrupeds, Whales. Nearly all are viviparous; a few (as the Opossum and other *Marsupials*) are *semi-oviparous*, the young at birth being very immature, and being therefore taken into a pouch (in Latin *marsupium* signifies *pouch*) where they draw nutriment from the mother until matured.

Class 2. — Birds. — Warm-blooded air-breathing animals, oviparous, having a covering of feathers, and the anterior limbs more or less perfect wings.

Class 3. — Reptiles. — Cold-blooded air-breathing animals, oviparous, having a covering of scales or simply a naked skin (as Crocodiles, Lizards, Turtles, Snakes); they breathe with lungs (or are air-breathing) when young as well as afterward, being, in this respect, like birds and quadrupeds.

Class 4. — Amphibians (as Frogs and Salamanders), which differ from true Reptiles in breathing by means of gills when young, and afterward becoming air-breathing, the animal undergoing, thus, a metamorphosis.

Class 5. — Fishes. — Cold-blooded oviparous animals, breathing by means of gills, and having a covering of scales or simply a naked skin. Among fishes: —

1. *Teliosts* (as the Perch, Salmon, and all common fishes) have the scales usually membranous, the skeleton bony, and the gills attached at only one margin.

The name is from the Greek *τέλειος* *perfect*, and *ὀστέον*, *bone*, alluding to the skeleton being all of it bony.

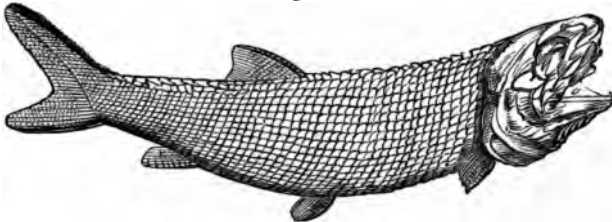
The scales in many are toothed or set with spines about the inner margin (Fig. 125), while others have the margin smooth (Fig. 124). Fishes having scales of the former kind, as the Perch, have been called *Ctenoids* by Agassiz (from the Greek *κτελς*, *comb*); and those having scales of the latter kind, as the Salmon, etc., *Cycloids* (from the Greek *κύκλος*, *circle*).

2. *Ganoids* (as the Gar-pike and Sturgeon), having the

scales bony and usually shining, and the skeleton often cartilaginous. The name is from the Greek *γάνος*, *shining*.

Fig. 120 represents one of the ancient Ganoids. The vertebral column extends to the extremity of the tail, so that the tail-fin is *vertebrated*, while, in modern Gars and Teliosts, the

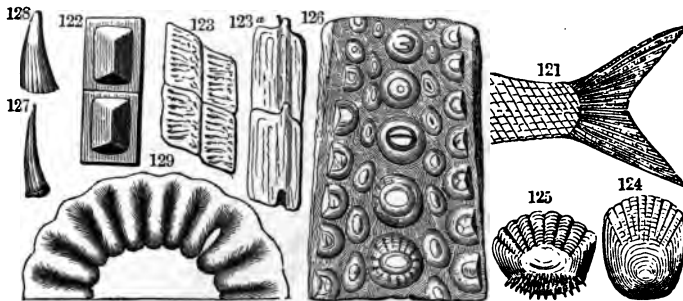
Fig. 120.



Palæoniscus Freieslebeni ($\times \frac{1}{2}$).

vertebral column stops at the commencement of the tail, or the tail-fin is *non-vertebrate* (Fig. 121). Agassiz called the

Figs. 121-129.



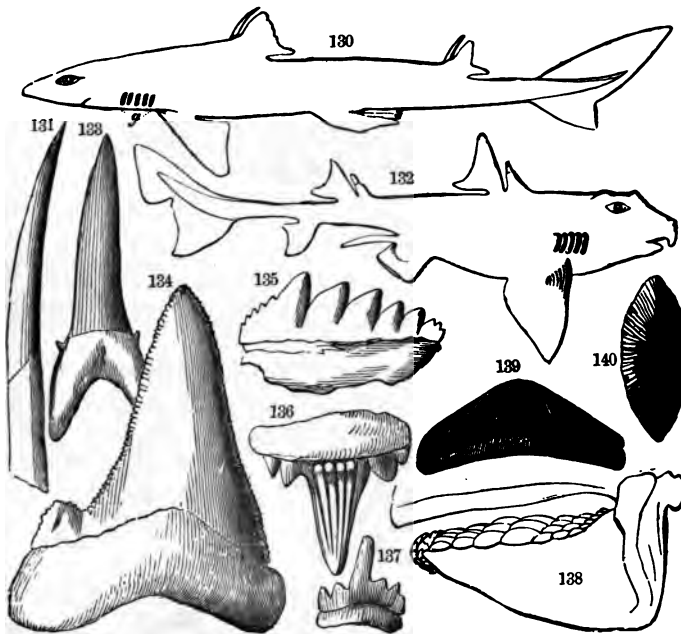
GANOIDS (excepting 124, 125). — Fig. 121, Tail of *Thrissops* ($\times \frac{1}{2}$); 122, Scales of *Cheirolepis Traillii* ($\times 12$); 123 *Palæoniscus lepidurus* ($\times 6$); 123, a, under-view of same; 124, scale of a *Cycloid*; 125, id. of a *Ctenoid*; 126, Part of pavement-teeth of *Gyrodus umbilicus*; 127, Tooth of *Lepidosteus*; 128, id. of a *Cricodus*; 129, Section of tooth of *Lepidosteus osseus*.

former kind *heterocercal*, and the latter *homocercal*. The scales are either rhombic, as in Figs. 121, or rounded. Some of these rhombic bony scales are shown also in Figs. 122, 123. The teeth (Figs. 127, 128) often have a folded or laby-

rinthine texture within, as in Fig. 129, representing a part of a section of a tooth enlarged. In one group, the Ganoids have a pavement of teeth in the mouth, as in Fig. 126.

3. **Selachians** (as the Sharks and Rays), having a hard skin, called *shagreen*, often rough with minute points, the skeleton

Figs. 130-140.



SELACHIANS. — Fig. 130, *Spinax Blainvillii* ($\times \frac{1}{2}$); 131, Spine of anterior dorsal fin, natural size; 132, *Cestracion Philippi* ($\times \frac{1}{2}$); 133, Tooth of *Lamna elegans*; 134, Tooth of *Carcharodon angustidens*; 135, *Notidanus primigenius*; 136, *Hybodus minor*; 137, *Hyb. plicatilis*; 138, Mouth of a *Cestracion*, showing pavement-teeth of lower jaw; 139, Tooth of *Acerodus minimus*; 140, Tooth of *Acerodus nobilia*.

more or less completely cartilaginous, and the gills attached by both margins. The name is from the Greek *σέλαχος*, *cartilage*.

Fig. 130 represents, much reduced, one of the order (a *Spinax*), having the mouth, as usual, on the under surface of the

head and remarkable for the spine before each of the back fins: one of the spines is shown, natural size, in Fig. 131. Fig. 132 is an outline of another Selachian, of the genus *Cestracion*, living in the vicinity of Australia, peculiar in having the mouth at the extremity of the head, and also in the teeth of the mouth having, in part, the form and appearance of a pavement, as shown in Fig. 138. Figs. 133 to 137 are teeth of different Selachians related to the Sharks; and Figs. 139, 140, pavement-teeth of Cestraciont species. The Cestraciont Selachians were once very common, but the tribe is now nearly extinct.

2. Sub-kingdom of Articulates.

Among Articulates there are three *classes*; *one*, including the species adapted to live on land, and which, for this purpose, breathe by means of air-vessels branching through the body; and *two*, of species adapted to live in water, and, therefore, having gills.

1. *Land Articulates*, or the class of INSECTEANS. There are three orders or grand divisions of Insecteans, namely: 1. *Insects*; 2. *Spiders*; 3. *Myriapods* (or Centipedes).

2. *Water Articulates*, including the two classes — 1. CRUSTACEANS (as Crabs, Lobsters, etc.), and 2. WORMS.

CRUSTACEANS.

A knowledge of the principal subdivisions of Crustaceans is especially important to the student in geology. There are three orders: —

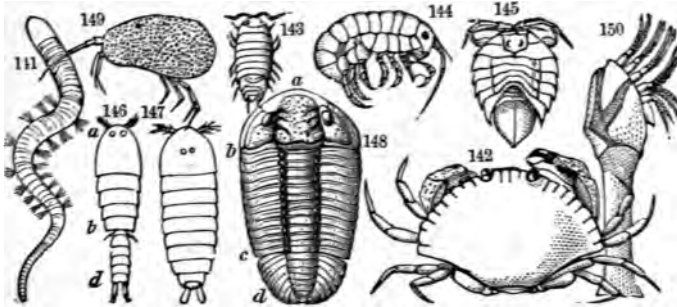
1. The **Decapods**, or 10-footed species, as the *Crab* (Fig. 142), *Lobster*, *Shrimp*.

2. The **Tetradecapods**, or 14-footed species, as the *Sow-bug* (Fig. 143), found in damp places under logs, the *Sand-flea* in the sands, or cast-up sea-weed of a beach (Fig. 144), etc.

3. The **Entomostracans**, or inferior species, having the feet defective, as the *Cyclops* and related species (Figs. 146, 147), *Daphnia*, *Limulus* or *Horse-shoe*, and the *Cypris* and other

Ostracoids (Fig. 149). These *Ostracoids* are generally minute species, having a shell like that of a bivalve Mollusk, as Fig. 104 shows; but inside of the shell, instead of an animal like a

Figs. 141-150.



ARTICULATES. — 1. *Worms*: 141, *Arenicola piscatorum*, or Lob-worm ($\times \frac{1}{2}$). 2. *Crustaceans*: 142, Crab, species of Cancer; 143, an Isopod, species of Porcellio; 144, an Amphipod, species of *Orchestia*; 145, an Isopod, species of *Serolis* ($\times \frac{1}{2}$); 146, 147, *Sapphirina Iris*, — 146, female, 147, male ($\times 6$); 148, Trilobite, *Calymene Blumenbachii*; 149, *Cythere Americana*, of the Ostracoid family ($\times 12$); 150, *Anatifa*, of the Cirriped tribe.

clam, there is one more like a shrimp, with jointed legs. The name is from the Greek *ὄστρακον*, *shell*, the word from which oyster is derived.

Among *Entomostracans*, there are also the Barnacles and other Cirripeds, one of which is represented in Fig. 150.

Trilobites (Fig. 148) are related to the *Limulus* or "Horse-shoe" among the lower Crustaceans. The tribe is intermediate in some points between Crustaceans and Scorpions. It is now extinct.

3 Sub-kingdom of Mollusks.

There are three grand divisions or classes of Mollusks: —

1. **Ordinary Mollusks**, as the *Clam*, *Snail*, and *Cuttle-fish*, which have branchiæ (gills).

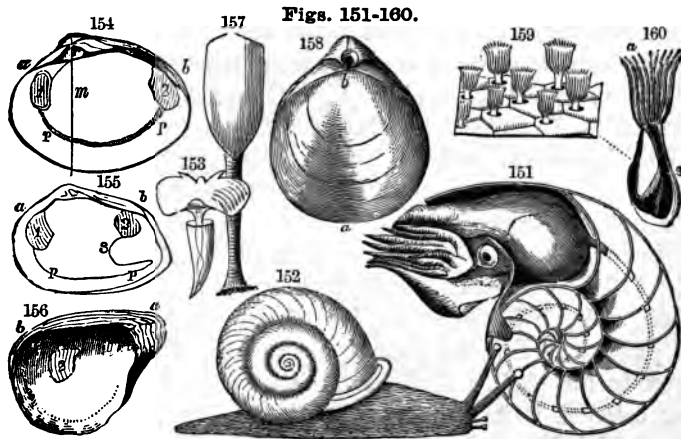
2. **Ascidian Mollusks**, which have no branchiæ and no distinct tentacles or arms, and which have only a leathery or membranous exterior, and therefore are not found among fossils.

3. **Brachiæ Mollusks**, which have two or more tentacles or

arms, with no branchiæ, and which are usually attached by a stem; many of which have two arms and a bivalve shell, and others a circle or spiral of tentacles or arms and thus resemble flowers (Figs. 159, 160), though *not radiate internally* like true Radiate animals.

1. Ordinary Mollusks. — These are of three orders: —

1. Cephalopods: having the head surrounded by arms, and large eyes; the shell, when any exists as an *external* covering for the body, is, with a rare exception, divided internally by



MOLLUSKS. — 1. *Cephalopods*: Fig. 151, Nautilus, showing the partitions in the shell and the animal in the outer chamber, — 2. *Gasteropods*: 152, Helix. — 3. *Pteropods*: 153, Cleodora. — 4. *Conchifers*: 154, 155, 156, the last, the oyster. — 5. *Brachiopods*: 157, Lingula, on its stem; 158, Terebratula, showing the aperture at *b*, from which the stem for attachment passes out. — 6. *Bryozoans*: 159, Eschara, with the animals a little enlarged; 160, one of the animals out of the shell, more enlarged.

cross-partitions into a series of chambers, whence they are called *chambered* shells, as in the Nautilus (Fig. 151) and Ammonite (page 296). A few have an *internal* chambered shell; others an *internal* straight bone, which has sometimes a conical cavity. The name is from the Greek κεφαλή, *head*, and πούς, *foot*.

2. Cephalates: having a head with distinct eyes, but no arms around it, and usually a spiral shell, if any; as the

Snail (Fig. 152) and other *Univalves*. The species of one division — that containing the Snail and all ordinary Univalves — are called *Gasteropods*, from the Greek γαστήρ and ποῦς, implying that they crawl on their ventral surface, — this part acting, therefore, as a *foot*. In another division, they have a pair of wing-like oars for swimming, and these are called *Pteropods* (Fig. 153), from the Greek πτερόν, *wing*, and ποῦς, *foot*.

3. *Acephals* (from *a*, *without*, and κεφαλή, *head*): having no prominent head, and only imperfect eyes, if any; and the shell commonly of two parts called valves, placed either side of the body, whence the common name of most of the species, *Bivalves*; as the *oyster*, *clam* (Figs. 154–156). These species are called *Lamellibranchs*, because they have thin *lamellar gills* either side of the body, from *lamella*, a *plate*, and *branchia*, a *gill*. The body has on either side a thin fold of skin called the *pallium*, or *cloak*.

In Fig. 154, showing the inside of a valve, 1, 2 are impressions of the two great muscles by which the animal closes the shell, and *pp* is the impression of the margin of the *mantle* or *pallium*, called the *pallial impression*. This mantle lies next to the shell, and the shell is secreted by it; the gills are between it and the body of the Mollusk. In Fig. 155, the pallial impression *pp* has a deep bend or *sinus* opening toward the back margin of the valve. Shells having this sinus in the impression are described as *sinupallial*, and those without it as *integripallial*. In Fig. 156, of the oyster, there is but one large muscular impression (at 2).

2. **Brachiote Mollusks.** — These are of two orders: —

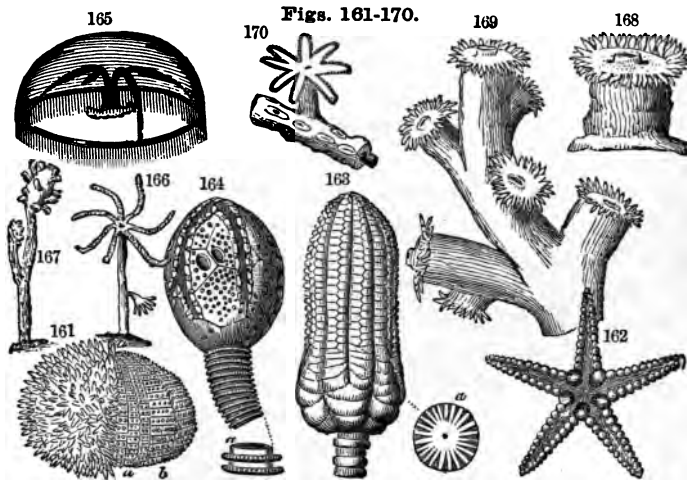
1. *Brachiopods*: species (Figs. 157, 158) having a bivalve shell, like the Lamellibranchs, but one of the valves *dorsal* (or over the back), and the other *ventral*, instead of being on the sides of the body; moreover, the form is symmetrical either side of a middle line; that is, if a line be dropped from the beak to the opposite edge (as from *b* to *a* in Fig. 158), the parts of the shell on the two sides of the line will

be equal. A line similarly drawn in the Lamellibranchs divides the valve unequally (as in Fig. 154). The animals have two spiral arms within, which serve as gills. The name *Brachiopod*, from the Greek *βραχίον*, *arm*, and *πούς*, *foot*, refers to these arms.

2. *Bryozoans*: species of minute size like a polyp in external form, making often cellular corals which, though often in thin plates or incrustations, sometimes delicately branch like a moss, whence the name, from the Greek *βρύον*, *moss*, and *ζῶον*, *animal*. They include the *Cellepores*, *Flustras*, etc. Fig. 159 shows a number of the animals protruded from their cells.

4. Sub-kingdom of Radiates.

There are three grand divisions of Radiates: —



RADIATES. — 1. *Echinoderms*: 161, Echinus, the spines removed from half the surface ($\times \frac{1}{2}$); 162, Star-fish, *Paleaster Niagarensis*; 163, *Crinoid*, *Encrinurus liliiformis*; 164, *Crinoid*, of the family of Cystideans, *Callocystites Jewettii*. — 2. *Acalephs*: 165, a Medusa, genus *Tiaropsis*; 166, Hydra ($\times 8$); 167, *Syncoryna*. — 3. *Polyps*: Fig. 168, an *Actinia*; 169, a coral, *Dendrophyllia*; 170, part of a branch of a coral of the genus *Gorgonia*, showing one of the polyps expanded.

1. **Echinoderms** (Figs. 161 to 164): having a more or less hard, inflexible exterior, which is often covered with spines, —

whence the name, from *ἐχῖνος*, a *hedgehog*, and *δέρμα*, *skin*. The mouth opens downward in all species except in some attached species. Among them are: 1. *Echinoids*, in which the exterior is a solid shell covered with spines, and the mouth opens downward (Fig. 161 — the spines are removed from half of the shell); 2. *The Asterioids*, or *Star-fishes*, in which the exterior is rather stiff, but still flexible, so that the animal flexes it in its movements (Fig. 162) and the viscera extend into the arms; 3. *The Crinoids* (including the *Comatulids*), having flexible arms like star-fishes, but the rays and body made of closely fitting solid calcareous pieces, and having in the Comatulids arms for attachment, and in the other Crinoids a stem and being thus plant-like.

Other kinds are the *Holothurioids*, which are much like the Echinoids in interior structure and the absence of arms, but have no hard exterior shell, and are seldom found fossil; and the *Ophiuroids*, or *Serpent-stars*, which are near the Asteroids, but have the arms very slender, with no groove beneath.

2. **Acalephs** (Figs. 165–167): having a soft, flexible body, usually of a jelly-like aspect, though rather tough, and moving, when free, with the mouth downward, as the *Medusæ* (Fig. 165). Some of the species called *Hydroid* Acalephs (Figs. 166, 167), in one of their stages, if not through all, look like Polyps; and some of these Acalephs form corals, like the Polyps. The *Millepores* are Acaleph corals. The other species are mostly too soft to be common as fossils.

3. **Polyps** (Figs. 168–170): having a soft body usually attached to a support; a mouth opening upward; one or more rows of tentacles arranged about the margin of a disk (somewhat like the petals of an Aster around its central disk); and the mouth situated at the centre of the disk, as in Fig. 168. Most corals are made by polyps. The coral is secreted *within* the polyp in the same manner as bones are secreted within other animals. Figs. 169, 170 represent portions of living corals with the polyps expanded. The number of rays in the cells of many modern corals (the *Actinoids*) is a multiple of

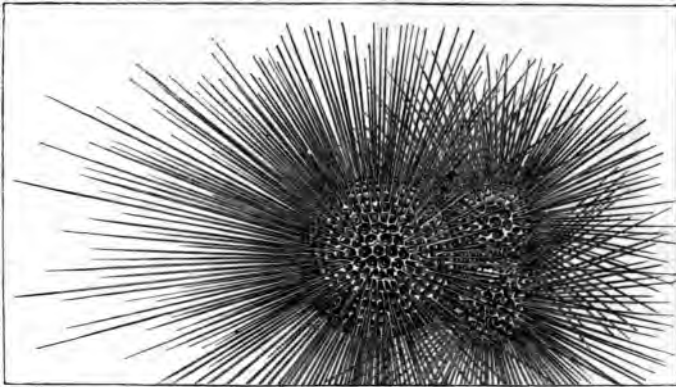
six; and that in many of the more ancient corals, those called *Cyathophylloids*, is a multiple of *four*.

5. Protozoans.

The subdivisions of Protozoans of geological importance are those of the Sponges and Rhizopods.

1. **Sponges.** — A sponge is an assemblage of minute Protozoans produced by growth from a single germ. The united animals secrete the horny fibre, and also, from an inner layer, its siliceous spicules (see p. 67), when these are present. In many the siliceous portion predominates; and in some (p. 314) the skeleton is wholly of silica.

Fig. 171.



Globigerina bulloides.

2. **Rhizopods.** — Rhizopods are so called from the Greek for *root-like feet*, because of the slender, thread-like appendages (pseudopodia, *false feet*) which in many species are made as they are protruded; they serve for taking food, and often also for digesting it. Those of special interest geologically are of two groups.

1. *Foraminifers*, which have *calcareous* shells (p. 65), made up usually of a group of cells spirally or alternately arranged

(Figs. 71 to 84, p. 66). The shells have minute pores (foramina) through which the threads are protruded. Fig. 172 represents a living species much enlarged, with its pseudopodia extended; and Fig. 171 the common *Globigerina* of the sea-bottom, also greatly enlarged; when alive and un-mutilated, the latter has its shell covered with spines, as in the figure, and its pseudopodia protruded along the spines (Wyville Thomson).

2. *Radiolarians* (or Polycystines), which have *siliceous* shells, as explained and illustrated on page 67. Fig. 173

Fig. 172.



Fig. 173.

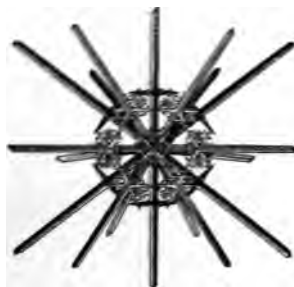


Fig. 172, *Rotella*, living Rhizopod with pseudopodia protruded; 173, *Xiphacantha* $\times$ 50, a Radiolarian.

represents another species which has radiating spines; although minute, it has some resemblance to the glass sponges. In these species the protoplasmic animal mass (absent in the figures) is collected about the centre, and from it the pseudopodia radiate outward.

II. Vegetable Kingdom.

The two most prominent subdivisions of Plants are those of (1) Cryptogams and (2) Phenogams.

The CRYPTOGRAMS, or *Flowerless plants*, have no true flowers, and hence the name from the Greek (*κρυπτός* and *γάμος*), referring to the concealed method of fructification. They

comprise the *Seaweeds*, *Mosses*, *Ferns*, etc. They produce *spores* in place of true seeds, the spore being a simple cellule, while true seeds have about the germ-cellule more or less of albumen and starch for the nutriment of the embryo plant.

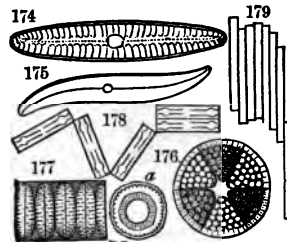
The PHENOGAMS, or *Flowering plants*, the term from the Greek (*φαίνω* and *γάμος*), referring to the open method of fructification; that is, by means of stamens and pistils, the central organs in flowers. All plants are here included that have flowers, from the grasses to the ordinary forest trees.

I. Cryptogams.—The lower Cryptogams consist of cellular tissue alone; the higher, like Phenogams, of both woody fibre and cellular tissue.

Lower Cryptogams of the following kinds (A) *have no leafy stems*: (1) *Algæ*, or *Seaweeds*, embracing all flowerless and leafless water plants; (2) *Fungi*, or the mushrooms, mould, etc.; (3) *Lichens*, the dry gray-green and gray to brown and black plants, growing in dry places, and often covering stones and the bark of trees. An exposed rocky bluff usually owes its color mostly to the lichens which cover it, and not to the rock constituting it. The following among the lower Cryptogams (B) *have leafy stems*: (1) *Mosses*, and (2) the *Liverworts*.

To the Algæ belong the microscopic *Diatoms* and *Desmids*, which are one-celled (unicellular) plants, living in both fresh and salt water. The Diatoms (Figs. 174–179, and 88, p. 68) are siliceous, as already explained. The Desmids are green, secrete no silica, and are often found fossil in flint and chert (Figs. 241–247, p. 234). They include also the calcareous *Nullipores* (p. 66), and semi-calcareous *Corallines*; and also the microscopic *Coccoliths* and *Rhabdoliths* (p. 66).

Figs. 174–179.



DIATOMS highly magnified; 174, *Pinnularia peregrina*; 175, *Pleurosigma angulatum*; 176, *Actinopterychus senarius*; 177, *a*, *Melosira sulcata*; 178, *Grammatophora marina*; 179, *Bacillaria paradoxa*.

Higher Cryptogams.—These Cryptogams, having bundles of woody tissue in the stems, are called *Acrogens*, (from the Greek *ἄκρον*, *top*, and *γεννάω*, *I grow*) because they grow upward and make stems, and in some cases high trees.

Acrogens are divided into (1) *Ferns*; (2) *Lycopods*, or Ground-pines; and (3) *Equiseta*, or Horsetails. Some tropical ferns are trees 10 to 30 feet high, having a broad star of large fronds at the top. Ground-pines have the foliage of miniature spruces or pines, and hence the name. In a former age they grew into trees 40 feet or more in height, closely resembling in aspect modern spruces or pines. The modern *Equiseta* (sometimes called *scouring-rushes*) are slender plants with hollow stems, a little rush-like in habit. The stems are jointed, and the divisions are easily broken apart at the joints. Ancient species, called *Calamites* (because of their reed-like form, from the Greek *κάλαμος*, *reed*), were 10 to 20 feet high.

II. Phenogams.—Phenogams, or Flowering plants, are divided into two sections, according to the mode of growth. (1) The *Exogens* (so named from the Greek *ἔξω*, *outward*, and *γεννάω*, *I grow*) have a bark separable from the wood, and grow by the addition of a layer to the adjoining surfaces of

the bark and wood each year, so that in a transverse section of a stem there are rings of growth (Fig. 180) marking the age of the stem. They include all our common trees and shrubbery and a large part of smaller plants. (2) The *Endogens* (so named from *ἔνδον*, *within*, and *γεννάω*), have no proper bark, and show

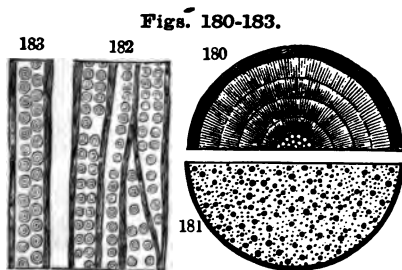


Fig. 180, section of exogenous stem; 181, id. of endogenous; 182, fibres of the Conifer, *Pinus Strobus*, showing dots, magnified 300 times; 183, same of *Araucaria Cunninghamii*.

in a transverse section of the stem the ends of bundles of

fibres of woody tissue with more or less of spongy cellular tissue (Fig. 181). They grow by additions to the bundles of woody fibre, progressing from the exterior toward the centre. They include the *palms, rattan, reed, grasses, indian corn*. When the bundles of fibres in a palm have reached the centre, the juices can no longer ascend, and the plant dies.

Phenogams are divided into the following groups:—

1. *Gymnosperms* (from *γυμνός*, *naked*, and *σπέρμα*, *seed*). — Growth exogenous; the flowers exceedingly simple, there being only one or two stamens, and the *seed naked*,—the seed in many species being on the inner surface of the scales of cones; as the *Pine, Spruce, Hemlock*, etc. The Gymnosperms include (1) the *Conifers*, or the Pine-tribe of plants, usually called evergreens; and (2) the *Cycads*, or plants related to the *Cycas* and *Zamia*, which have the leaves of a Palm (page 288), although, in fruit and wood, true Gymnosperms.

The wood of the Conifers is simply woody fibre without ducts, and in this respect, as well as in the naked seed and very simple flowers, this tribe shows its inferiority to the following subdivision. The fibres of Coniferous wood may be distinguished, even in petrified specimens, by the dots (Fig. 182) along their surface, as seen under a high magnifier. The dots look like holes, though really only thinner spaces. In one division of the Conifers, called the *Araucariæ*, of much geological interest, these dots are alternated (Fig. 183).

2. *Angiosperms* (from *ἀγγεῖον*, *vessel*, and *σπέρμα*, *seed*). — Growth exogenous; the seed covered or contained in a seed-vessel; as the *Maple, Elm, Apple, Rose*, and most of the ordinary shrubs and trees.

3. *Endogens*. Growth endogenous, as above explained. The flowers of Endogens include some of the most beautiful kinds, as those of the Lily tribe, Orchids, etc.; and the edible products exceed in value those of all other plants,—grasses with wheat, indian corn, and other grains, being included, as well as the fruits of several kinds of palm, banana, pine apple, and other species.

PART IV.

HISTORICAL GEOLOGY.

HISTORICAL GEOLOGY treats of the order of succession in the strata of the earth's crust, and of the changes that were going on during the formation of each bed or stratum,—that is, of the changes in the oceans and the land; of the changes in the atmosphere and climate; of the changes in the plants and animals. In other words, it is an historical view of the events that took place during the earth's progress, derived from the study of the successive rocks. It is sometimes called *stratigraphical* geology; but this term embraces only *a description of the nature and arrangement of the earth's strata.*

By using the means for determining the order of the several formations mentioned on page 58, and by a careful study of the organic remains (as fossils are often called) contained in the rocks, from the oldest to the most recent, it has been found that a number of great *ages* in the progress of this life, and in other events of the history, can be made out.

The following have thus been recognized:—

1. There was *first* an age, or division of time, when there was no life on the globe; or, if any existed, this was true only in the later part of the age, and the life was probably of the very simplest kinds.
2. There was next an age when Shells or Mollusks, Corals, Crinoids, and Trilobites abounded in the oceans when the

continents were almost all beneath the salt waters, and when there was, throughout its larger part, as far as fossils show, no fishes and no terrestrial life.

3. There was next an age when, besides Shells, Corals, Crinoids, Trilobites, and Worms, Fishes were numerous in the waters, and when the lands, though yet small, were more or less covered with vegetation.

4. There was next an age when the continents were at many successive times largely dry or marshy land, and the land was densely overgrown with trees, shrubs, and smaller plants, of the remains of which plants the great coal-beds were made. In animal life there were, besides the kinds already mentioned, various Amphibians and some other Reptiles of inferior tribes.

5. There was next an age when Reptiles were exceedingly abundant, far outnumbering and exceeding in variety, and many also in size and even in rank, those of the present day.

6. There was next an age when the Reptiles had dwindled, and Mammals or Quadrupeds were in great numbers over the continents.

7. After this came Man; and the progress of life here ended.

The above-mentioned ages in the progress of life and the earth's history have received the following names:—

1. **Archæan Time or Age.**—The name is from the Greek for *beginning*.

2. **Age of Invertebrates**, or the **Silurian Age**.

3. **Age of Fishes**, or the **Devonian Age**.

4. **Age of Coal-Plants**, or the **Carboniferous Age**.

5. **Age of Reptiles**, or the **Reptilian Age**.

6. **Age of Mammals**, or the **Mammalian Age**.

7. **Quaternary Age**, or the **Age of Man**.

The first of these ages—the *Archæan*—stands apart as preparatory to the age of Invertebrates, or the Silurian, when the systems of life, excepting the Vertebrate, were well displayed.

The Silurian, Devonian, and Carboniferous ages were alike in many respects, — especially in the aspect of antiquity pervading the tribes that then lived, the shells, crinoids, corals, fishes, coal-plants, and reptiles belonging to tribes that are now wholly or nearly extinct. The era of these ages has, therefore, been appropriately called *Paleozoic time*, the word *Paleozoic* coming from the Greek *παλαιός*, *ancient*, and *ζωή*, *life*.

The next age was ushered in after the extinction of many of the Paleozoic tribes; and its own peculiar life approximated more to that of the existing world. Yet it was still made up wholly of extinct species, and the most prominent of the tribes and genera disappeared before or at its close. This age corresponds to *Mediæval time* in geological history, and is called *Mesozoic time*, from the Greek *μέσος*, *middle*, and *ζωή*, *life*.

The next age, as well as the last, was decidedly modern in the aspect of its species, the higher as well as lower. Both are included under the division called *Cenozoic time*, from the Greek *καινός*, *recent*, and *ζωή*, *life* (the *ai* of Greek words always becoming *e* in English, — as, for example, in *ether*, from the Greek *αιθήρ*).

The following are, then, the grand divisions of geological time adopted: —

I. Archæan Time.

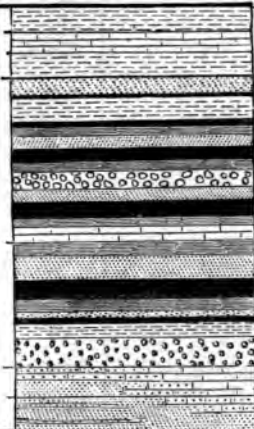
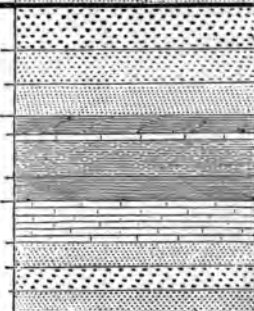
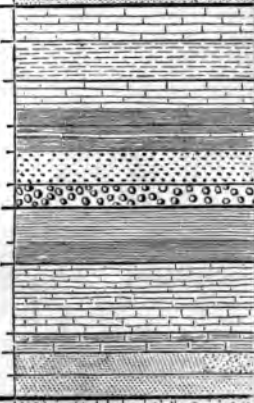
II. Paleozoic Time, including, 1. *The Age of Invertebrates*, or *Silurian*; 2. *The Age of Fishes*, or *Devonian*; 3. *The Age of Coal-Plants*, or *Carboniferous*.

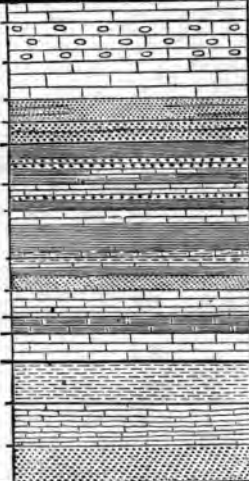
III. Mesozoic Time, including the *Reptilian Age*.

IV. Cenozoic Time, including the *Tertiary* and *Quaternary Ages*.

The following sections represent the successive formations of the globe, arranged in the order of time, with the subdivisions corresponding to the Ages and Periods.

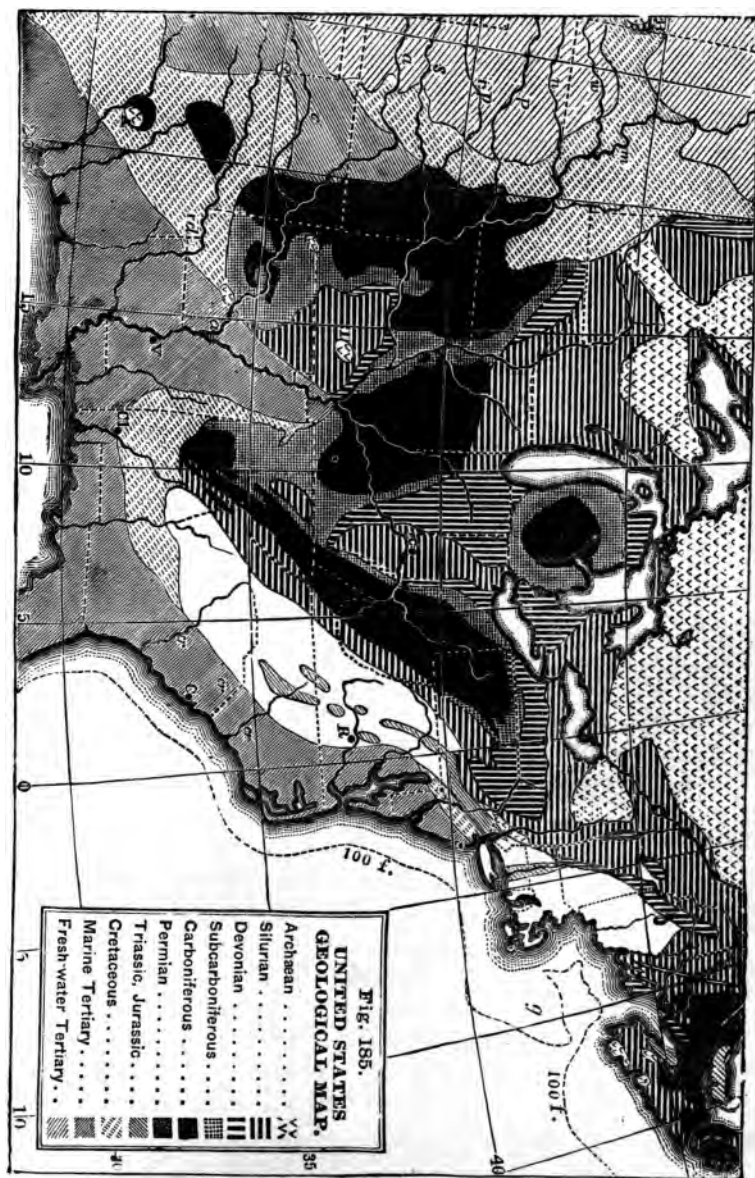
AGES. Fig. 184. — PALEOZOIC. AMERICAN PERIODS. FOREIGN SUBDIVISIONS.

Carboniferous Age, or Age of Coal Plants.		15. Permian.	Permian.
		14. Carboniferous, or Coal-Measures.	Carboniferous, or Coal-Measures.
		13. Subcarboniferous.	Mountain limestone.
Devonian Age, or Age of Fishes.		12. Catskill.	Old Red Sandstone.
		11. Chemung.	
		10. Hamilton.	
		9. Corniferous.	
		8. Oriskany.	
Silurian Age, or Age of Invertebrates.		7. Lower Helderberg.	Ludlow beds.
		6. Salina.	
		5. Niagara.	Wenlock beds. Upper Llandovery.
		4. Trenton.	Caradoc sandstone. Bala Limestone. Llandovery group.
		3. Canadian.	Tremadoc slates. Skiddaw slates.
		2. Primordial.	Primordial, Cambrian.
		1. Archaean.	

AGES.		Fig. 184. (continued)	PERIODS.	FOREIGN SUBDIVISIONS.
Cenozoic Time.	Quaternary, or Age of Man.		Recent. Champlain. Glacial.	Recent. Quaternary, or Pleistocene.
	Tertiary, or Age of Mammals.		Pliocene. Miocene. Alabama. Lignitic.	Pliocene. Miocene. Eocene.
Age of Reptiles, or Mesozoic Time.			Cretaceous. ✓	Upper Cretaceous. Middle Cretaceous. Lower Cretaceous.
			Jurassic. ✓	Wealden. Oolite. Lias.
			Triassic.	Keuper. Muschelkalk. Bunter-sandstein.

In the preceding sections, *Archæan* is at the bottom, on the left; above it there are the names *Silurian*, *Devonian*, and so on; and the names of the Periods, *Primordial*, *Canadian*, *Trenton*, etc., dividing off these Ages, on the right.

The names of the Periods in the first part of the section (those of the *Paleozoic*), the first excepted, are derived from the names of American rocks or localities. The names on the other part are mostly European, as the series of rocks it contains (those of *Mesozoic* and *Cenozoic* time) are more complete in Europe than in America.



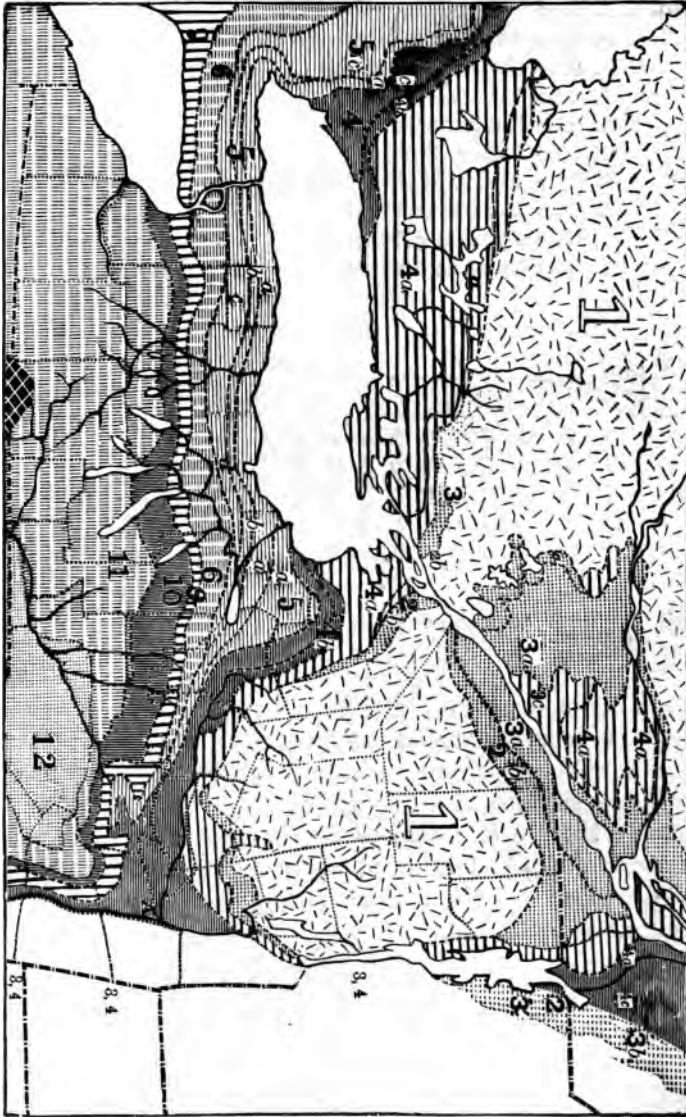
The various strata in the formations of an age are very diversified in character, limestones being overlaid abruptly by sandstones, conglomerates, or shales, or either of these last by limestones; and each may be very different from the following in its fossils. These abrupt transitions in the strata are proofs that there were great changes at times in the conditions of the region where the strata were formed, and the transitions in the kinds of fossils are evidence of great destructions at intervals in the life of the seas. Such transitions, therefore, naturally divide off the ages into smaller portions of time, or *periods*, as they are called. By transitions similar in kind, but not so great, *periods* may often be subdivided into still smaller parts, or *epochs*.

The map on page 195 represents the distribution of the rocks of the different ages, as surface-rocks, over the United States and Canada. The areas indicated by the different kinds of lining are stated on the map.

The areas left white are of unascertained or doubtful age; *cr.* marks outcrops of Cretaceous on the Atlantic border; C., Cincinnati; Cl., Claiborne; V., Vicksburg.

The Silurian strata may underlie the Devonian, and both Silurian and Devonian the Carboniferous. The black areas of the Carboniferous period do not, therefore, indicate the absence of Devonian and Silurian, but only that the Carboniferous strata are the *surface* strata over the region. There may even be exceptions to this remark with regard to the *surface* strata; for, over the areas thus marked Carboniferous, older rocks may occur in some of the bluffs along the valleys, or occupy small areas in the region, which are too limited to be noted on so small a map.

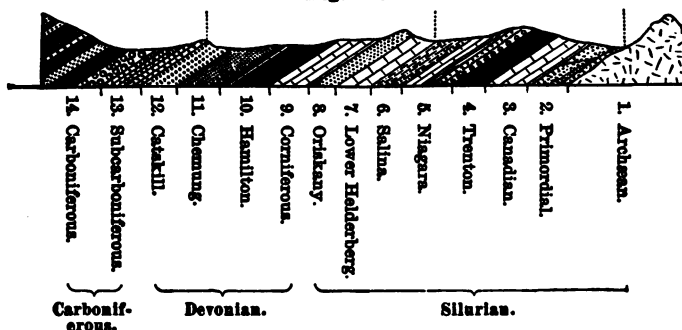
The map on page 197 represents the surface-rocks of the State of New York and Canada, the several areas corresponding to the *periods*. For the Silurian, the lines or dots are drawn *horizontally*, as in the preceding, and for the Devonian, *vertically*. There is no Carboniferous, except near *the southern* border of the State of New York.



186.—Geological Map of New York and Canada.

- | | |
|--|--------------------------|
| No. 1. The Archæan. | |
| 2. The Primordial Period. | } Lower Silurian. |
| 3. The Canadian Period. | |
| 4. The Trenton Period. | } Upper Silurian. |
| 5. The Niagara Period. | |
| 6. The Salina Period. | } Devonian. |
| 9. The Upper Helderberg Period. | |
| 10. The Hamilton Period. | |
| 11. The Chemung Period. | |
| 12. The Catskill Period. | |

Fig. 187.



In the section in Fig. 187, the rocks of the successive periods are represented in order, from the Archæan, in Northern New York, southwestward to the Coal-formation of Pennsylvania, showing that they succeed one another on the map simply because *they come to the surface in succession*. The amount of dip and its regularity are greatly exaggerated in the section; and there is no attempt to give the relative thickness of the beds.

I.--ARCHÆAN TIME.

1. Rocks: Kinds and Distribution.

1. Distribution. — The Archæan era commenced with the origin of the earth's crust, and includes the oldest rocks of the globe. Its formations are those upon which the fossiliferous rocks of the Silurian and subsequent ages have been spread out, and the material out of which most of these later rocks have been made.

The Archæan rocks extend around the whole sphere; but,

Fig. 188.



Archæan Map of North America.

in general, they are concealed from view by subsequent formations. In North America they are *surface* rocks over a large area north of the great lakes, shaped like the letter V,

the longer branch of which area runs northwest to the Arctic Ocean, and the shorter, northeast to Labrador. The white area on the preceding map, in what is now British America, is the portion of the continent here referred to. There is also a small Archæan area in Northern New York (see map page 197); the Highlands of Putnam County, New York, and of New Jersey is Archæan, and so also in part the Blue Ridge of Virginia; another south of Lake Superior; and a few other spots east of the Rocky Mountains. Some high ranges also of the Rocky Mountain region are Archæan.

In Europe Archæan rocks are in view in the great iron regions of Sweden and Norway, in Bohemia, and in Scotland.

2. Kinds of Rocks. — The rocks are mostly *crystalline* rocks, such as granite, syenite, gneiss, syenitic gneiss, mica schist, hornblende schist, chlorite slate, and granular limestone. But besides these there are some hard conglomerates, quartz-rocks or gritty sandstones, and slates. The beautiful iridescent feldspar called *labradorite* (page 22) is a common constituent of some of the coarse crystalline or granitic rocks.

An abundance of iron is one characteristic of the beds. The rocks very often contain hornblende, an iron-bearing mineral, or black mica, also iron-bearing. Along with the rocks there are, in some regions, immense beds of *iron ore* (*i i i*, in Fig. 189). In Northern New York the beds are 100 to 200 feet thick. Similar iron-ore beds occur in New Jersey, Michigan, south of Lake Superior, and in Missouri. *Graphite* is common in some places, and constitutes 2 to 30 per cent of some beds, especially of the limestones.

Fig. 189.



3. Disturbance and Crystallization of the Rocks. — The layers of gneiss and other schistose rocks, with the included limestones, are nowhere horizontal; but, instead of this, they dip at all angles, and are often flexed or folded in a most complex manner. Fig. 190 represents the folded character of the Archæan rocks of Canada. The folded rocks in this

figure are overlaid by beds that are nearly horizontal, which belong to the Lower Silurian.

Owing to the discolations and uplifts which the rocks have undergone, the iron-ore beds look like veins; and even the strata of crystalline limestone have often a similar vein-like

Fig. 190.



Fig. 190, by Logan, from the south side of the St. Lawrence in Canada, between Cascade Point and St. Louis Rapids; 1, Archæan gneiss; 2, Silurian strata.

appearance. Where strata have been thrown up so that the layers stand vertical, the included bed of ore will be vertical also, and will descend downward in the same manner as a true metallic vein; and through the breaking and faulting of the strata many of those irregularities would result that are so common in veins.

Gneiss, mica schist, granular limestone, and other crystalline rocks have been described on page 35 as *metamorphic* rocks,—rocks that were once horizontal sandstones, shales, and stratified limestones, and which have been, by some process, *crystallized*. The gneiss and schists in Archæan regions, although upturned at all angles, are actually in layers or strata alternating with one another, as common with ordinary sandstones and shales; and the ore-beds are conformable to the layers of schist and quartzite in which they occur.

4. Conclusions as to the Origin of the Rocks.—The following conclusions hence follow: 1. That the Archæan rocks here referred to were originally horizontal strata of sandstones, shales, and limestones; 2. That after their formation they were pushed out of place by some great movement of the earth's crust, which uplifted and folded them, so that now they are nowhere horizontal; 3. That, besides being displaced, they were also crystallized,—that is, changed into *metamorphic* rocks.

The thickness of the Archæan rocks of Canada is stated to exceed 30,000 feet. So great an accumulation of marine beds is proof that the era was very long.

It is altogether probable that the time of the uplifting and that of the metamorphism were the same. There may have been many such metamorphic epochs in the course of Archæan time. But, since even the latest beds of the Archæan are thus upturned and crystallized, an extensive revolution of this kind must have been a closing event of the age. Fig. 190 shows that the upturning preceded the formation of the lowest Silurian beds, for these lie undisturbed over the folded and crystallized Archæan.

Below the surface Archæan rocks there must be others, constituting the *interior portions of the earth's crust*. If the earth were originally a melted globe, as appears altogether probable, the earth's crust is its cooled exterior. Whenever the crust formed, its surface must have been at once worn by the waves, wherever within their reach, and deposits of sand, pebbles, and clay must have been formed; and in this way the Archæan formations were begun. But at the same time that these surface strata were in progress, the crust would have been increasing in thickness within by the cooling which was continuing its progress. Of the *interior* rock of the crust little is known.

2. Life.

The Archæan rocks contain no distinct fossil-plants. If plants existed then, they were *Sea-weeds*; for remains of none higher than sea-weeds occur in the overlying Lower Silurian formations. It is possible that *Lichens* existed over the exposed rocks; for such plants away from waters would not have left their remains in the mud or sands of the seas. There may also have been *Fungi* of simple kinds. But there is reason to believe that Mosses and higher plants were all absent, for none of these have been found in any Lower Silurian strata.

The *graphite*, abundant in some beds in Canada, is probable evidence of the existence of plants, because it is known that

in later times graphite has been formed out of their remains. The limestone beds suggest the idea that there was present either vegetable or animal life; for almost all limestones (see page 63) are of *organic* origin.

The annexed figure represents what has been regarded as a fossil form, and named *Eozoon Canadense*. It is supposed to have been a coral-like mass made by Protozoans of the class of Rhizopods, the simplest of all kinds of animal life. Each dark layer in the mass is supposed to mark the position of the animals. Its animal nature has not, however, been placed beyond doubt. Still, it is altogether probable that Rhizopods existed in the waters before the close of the Archæan era, and that the beds of limestone have been made of their minute shells, or else of calcareous Nullipores.

Fig. 191.



Eozoon Canadense.

3. General Observations.

The large Archæan area on the map, page 199, represents the main portion of the dry land of North America in the later part, or at the close, of the Archæan age; for it consists of the rocks made during the age, and is bordered on its different sides by the earliest rocks of the next age. It is the outline, approximately, of *Archæan North America*, or the continent as it appeared when the Silurian age opened. It is, therefore, the beginning of the dry land of North America, the original nucleus of the continent. The smaller Archæan areas mentioned appear to have been mountain ridges and islands in the great continental seas.

Europe had its Archæan lands at the same time in Scandi-

navia, Scotland, Bohemia, and some other points; and probably each of the other continents was then represented by its spot, or spots, of dry land. All the rest of the sphere, excepting these limited areas, was an expanse of waters.

The facts to be presented under the Silurian age teach that the great but yet unmade continents, although so small in the amount of dry land, were not covered by the *deep* ocean, but only by comparatively *shallow* oceanic waters. They lay just beneath the waves, already outlined, prepared to commence that series of formations — the Silurian, Devonian, Carboniferous, and others — which was required to finish the crust for its ultimate continental purposes. Portions may have been at times a few thousands of feet under water, but in general the depth was small compared with that of the ocean.

We thus gather some hints with regard to the geography of America in the period of its first beginnings.

The outlines of the Northern Archæan area on the map, page 199 — the embryo of the continent — and the directions of the other Archæan lands are *very nearly parallel* to the coast lines of the present continent. The Archæan lands, both in North America and Europe, are largest in the more northern latitudes.

II. — PALEOZOIC TIME.

PALEOZOIC TIME includes three ages : —

1. The **Age of Invertebrates**, or **Silurian Age**.
2. The **Age of Fishes**, or **Devonian Age**.
3. The **Age of Coal-Plants**, or **Carboniferous Age**.

In describing the rocks of these ages over North America, and the events connected with their history, there are *four distinct regions* to be noted, — distinct, because in an important degree independent in their history. These are, —

1. The **Eastern border region**, or that near the Atlantic border, including Central and Eastern New England, New Bruns-

wick and Nova Scotia, and the coast region south of New York.

2. **The Appalachian region**, or that now occupied by the Appalachian Mountain chain, from Labrador on the north, along by the Green Mountains, and the continuation of the heights through New Jersey, Pennsylvania, Virginia, Eastern Tennessee, and so southwestward to Alabama.

3. **The Interior Continental region**, or that west of the Appalachian region, continued over much of the present eastern slope of the Rocky Mountain chain.

4. **The Western border and Rocky Mountain region**, from the crest of the Rocky Mountains westward.

I. AGE OF INVERTEBRATES, or SILURIAN AGE.

This Age is called Silurian from the region of the ancient Silures in Wales, where the rocks occur. It was first so named by Murchison.

The Age is naturally divided into *Lower* and *Upper* Silurian, each corresponding, in America, to three periods, thus:—

1. Lower Silurian.

1. *Primordial, or Cambrian Period*: including the Cambrian of England, with the Lingula flags.

2. *Canadian Period*: including the Tremadoc slates, the Skiddaw slates, and Stiper-stones group of Great Britain.

3. *Trenton Period*: including the Llandeilo flags, Bala limestone, and Caradoc sandstone of Great Britain.

2. Upper Silurian.

1. *Niagara Period*: including the Wenlock beds of Great Britain, with the Upper Llandovery.

2. *Salina Period*.

3. *Lower Helderberg Period*: including part of the Ludlow beds of Great Britain.

4. *Oriskany Period*: including the upper part of the Ludlow beds.

1. Primordial Period.

1. Rocks: Kinds and Distribution.

The strata of the Primordial period, in America, over the *Interior Continental* basin, are exposed to view at intervals from New York to the Mississippi River; beyond the river, over some parts of the eastern and western slopes of the Rocky Mountains; and also in Texas. The area on the map of New York and Canada (page 197) is that numbered 2, lying next to the Archæan. There is reason to believe, from the many points at which the strata come to the surface, that they extend over the larger part of the continent outside of the Archæan area represented on the map, page 199 though concealed by other less ancient strata over most of the surface.

Through the Interior region the lower rocks are in part a sandstone,—called the *Potsdam sandstone*, from a locality in Northern New York. The sandstone beds contain, in many places, ripple-marks (Fig. 24, page 46); mud-cracks (Fig. 26); layers showing the wind-drift and ebb-and-flow structure (Figs. 22 *f*, *e*); worm-burrows, and also occasionally the tracks of some of the animals of the period.

In the Appalachian region in Vermont, north in Canada, and in Pennsylvania, etc., the rocks are slates overlying sandstone, along with some limestone, the whole 2,000 to 7,000 feet or more thick.

In the Eastern border region beds of the period occur at Braintree, near Boston, at St. John's, New Brunswick, and on the Labrador coast. These are the oldest of American Primordial rocks, and have been distinctively called the *Acadian* group.

In Great Britain the Primordial rocks are hard sandstones and slates. The uppermost include the *Lingula* flags. They are most extensively in view in North and South Wales and in Shropshire. The lower portion of the series, of great thick-

ness, consisting of slates and other rocks, was named *Cambrian* by Sedgwick.

In Lapland, Norway, Sweden, and Bohemia, Primordial strata have been observed. If the strata of later date could be removed from the continents, we should probably find the Primordial beds extensively distributed over all the continents.

2. Life.

These most ancient of fossiliferous rocks contain no remains of *terrestrial* life. The *plants* of the period that left traces in the rocks were all *Sea-weeds*. Among *animals*, the sub-kingdoms of *Radiates*, *Mollusks*, and *Articulates* were represented by *water-species*, and by these only; there is no evidence that there were any *Vertebrates*.

The older sandstone abounds in many places in a shell smaller, in general, than a finger-nail, related to the modern *Lingula* (Fig. 192). It is the shell of a Mollusk of the tribe of Brachiopods. It stood on a stem, when alive, as represented in Fig. 157, page 181. These shells are so characteristic of the beds in many regions as to have suggested the name *Lingula flags*, or *Lingula sandstone*. Among Mollusks there were only Brachiopods for the greater part of the Primordial period; but in the later division appear some species of Lamellibranchs, Pteropods, Gasteropods, and Cephalopods.

Another tribe very prominent among the earliest of the earth's animals is that of *Trilobites*, of the sub-kingdom of Articulates, and class of Crustaceans.

One of the largest of them, and a kind characteristic of the Lower or Acadian division of the Primordial, is represented in Fig. 193, one sixth the natural size. Its total length, when living, must have been eighteen inches or more, and hence it was about as large as any living Crustacean. The specimen figured was found at Braintree, south of Boston. As shown, it had large eyes situated on the head-shield,—evidence,

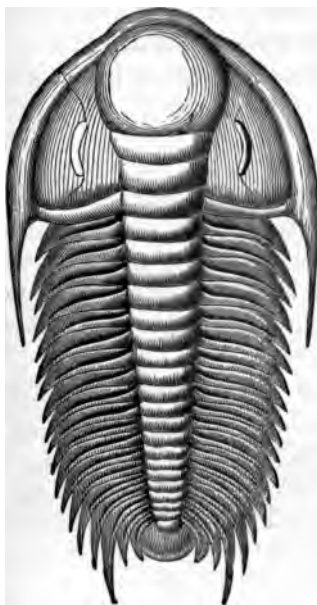
Fig. 192.



*Lingulella
prina.*

like other points in the structure that the species, although of the earlier division of the Primordial, were far removed from

Fig. 193.



TRILOBITE.—*Paradoxides Harlani*
($\times \frac{1}{2}$).

Scolithus linearis. These worm-holes are common in the European as well as American Primordial sandstones.

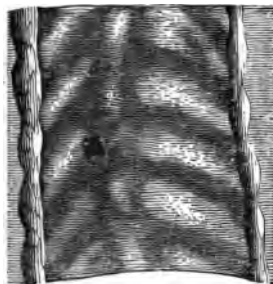
There were also *Crinoids* of the sub-kingdom of Radiates (page 65), for disks from the broken stems of Crinoids are not uncommon. And among Protozoans there were *Sponges*, and probably the minute *Rhizopods* (page 66).

Sponges among *Protozoans*, Crinoids among *Radiates*,

simple germ-like forms. Trilobites are supposed to have had membranous or foliaceous plates for swimming. Fig. 194 shows the track of a large animal (reduced to one sixth) found by Logan in the Canada beds, which may have been made by one of the great Trilobites as it crawled over the sand.

The existence of marine *worms* among the earliest animals of the globe is proved by the great numbers of worm-holes or burrows in the sandstones, now filled with hard sandstone like that of the rock. They are very similar to the holes made by such worms in the sands of sea-shores at the present time. One species has been called

Fig. 194.



Track of a Trilobite ($\times \frac{1}{6}$).

Brachiopods and some representatives of other tribes among *Mollusks*, Worms and Trilobites among *Articulates*, and Sea-weeds among *Plants*, make up the living species thus far discovered; and in this Primordial population, Trilobites took the lead. There is as yet no evidence that the dry Primordial hills bore a Moss or Lycopod, or harbored the meanest Insect, or that the oceans contained a single Fish.

3. General Observations.

The ripple-marks, mud-cracks, and tracks of animals preserved in this most ancient of Paleozoic rocks are records left by the waves, the sun, and the life of the period, as to the extent and condition of the continent in that early era. These markings teach that when the beds were in progress a large part of the continent lay at shallow depths in the sea, so shallow that the waves could ripple its sands; that over other portions the surface was a sand-flat exposed at low tide; or a sea-beach, the burrowing-place of worms; or a mud-flat, that could be dried and cracked under the heat of the sun, or in a drying atmosphere.

With such evidences of shallow water or emerged flats in a formation extending widely over the continent, it is a safe conclusion that the North American continent was at the time in actual existence, and probably not far from its present extent; and, although partly below the sea-level, and in some places deeply so, it was generally at shallow depths. The same may prove to have been true of the other continents. There is, in fact, evidence of other kinds which, taken in connection with the above, leaves little doubt that the existing places of the deep ocean and of the continents were determined even in the first formation of the earth's crust in the early Archæan era, and that, in all the movements that have since occurred, the oceans and continents have never changed places.

This preservation of markings, seemingly so perishable, on the early shifting sands, is a very instructive fact. They

illustrate part of the means by which the earth has, through time, been recording its own history. The track of a Trilobite, or of a wavelet, is a mould, in sand or earth, into which other sands are cast both to copy and preserve it; for if the waves or currents that succeed are light, they simply spread new sands over the indented surface, without obliterating the mould; and so the addition of successive layers only buries the markings more deeply and thus protects them against destruction. When, finally, consolidation takes place, the track or ripple-mark is made as enduring as the rock itself.

After the formation in North America of the great Primordial sandstone, there was a change in the condition of the surface, especially over the interior of the continent. For limestone strata began then to form where sandstones were in progress before. This change was probably some increase in the depth and clearness of the Interior Continental sea. Along the borders of this sea—that is, in New York and along the Appalachian region from Quebec into Virginia—the rock was a sandstone or shale, with some subordinate strata of limestone.

2. Canadian and Trenton Periods.

The CANADIAN period is so named from Canada, where the rocks are well displayed and have been most thoroughly studied; and the TRENTON period, from Trenton Falls, just north of Utica, the river at the Falls running between high bluffs of Trenton limestone.

In Great Britain the first of these periods covers the era of the Tremadoc and Skiddaw slates, and the latter that of the Bala limestone and Llandeilo flags.

1. Rocks: Kinds and Distribution.

In the Primordial period the rock deposits formed over the North American continent were mainly of sands or mud,

making sandstones and shales; and but little limestone was formed. The Canadian period is one of transition to a third, the Trenton, when limestones were in progress over nearly the whole breadth of the continent, the Appalachian and Arctic regions, as well as the Interior Continental.

The rocks of the Canadian period to the eastward in New York and Canada are, — 1. A sandstone associated in places with much limestone, and called, in allusion to the limestone, the Calciferous sand-rock; 2. South of Quebec, shale, sandstone, and thin beds of limestone, called the Quebec group; 3. A limestone formation, called the Chazy limestone, from a place of that name in Northern New York. The latter limestone (with probably beds of the Quebec group) makes part of the granular limestone or marble of the Green Mountains from Vermont to Connecticut, and has great thickness also in Pennsylvania and Virginia. In the Interior basin the rock of the period is mainly limestone — in Iowa and Wisconsin the Lower Magnesian limestone — excepting to the north, where the upper part is sandstone (St. Peter's sandstone) and along the south side of Lake Superior, where there is only sandstone. The "Pictured Rocks" and the thick sandstones of Keweenaw Point, remarkable for their intersection by trap dikes and veins of copper, have been supposed to be of this period, but are probably Primordial.

The Trenton period is remarkable for its extensive limestone formation. The limestone occurs in Canada; in New York (the beds at Trenton Falls giving it its name); along the Appalachian range; in Ohio and other States of the Ohio and Mississippi basin; from Wisconsin, northwestward along the west side of the Archæan area; and in the Arctic regions. It is in most places full of fossils. The "Birdseye" and "Black River" limestones are part of the Trenton formation. The rock of the *later part* of the Trenton period (called the Cincinnati epoch), in New York, and the Appalachians, is shale and sandstone, and even in the Interior basin the limestones are often, as about Cincinnati, quite clayey or impure. The *Utica*

shale and *Lorraine shale* belong to this era. The crystalline limestone (marble) of Vermont and Western Massachusetts and Connecticut, with the associated hydromica slate, clay-slate, mica schist, and quartzite, is Lower Silurian; it contains, at several localities in Vermont, Canadian and Trenton fossils.

The thickness of the rocks of the Canadian and Trenton periods in Pennsylvania is over 7,500 feet; while in Illinois it is but 750 feet, and in Missouri about 2,000 feet.

The rocks of this era in Great Britain are shales and shaly sandstones, with but little limestone. The Tremadoc slates are dark slates over 1,000 feet thick in Wales, passing below into the *Lingula* flags, and above into the Llandeilo beds. The Llandeilo flags are shaly sandstones; and, together with the associated shales, they have a thickness of many thousand feet. Above them there are the Caradoc sandstone of Shropshire, and the Bala formation, the latter sandy slates and sandstone, with thin beds of limestone, in Wales. In Scandinavia the rocks are limestone, overlaid by slates and flags; and in the Baltic provinces of Russia—part of the *Interior Continental* portion of the Eastern Continent—they are mainly limestones.

2. Life.

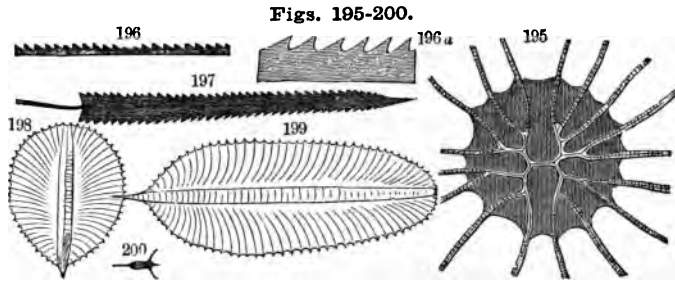
The life of these periods, like that of the Primordial, was, as far as evidence has been collected from the American or foreign rocks, marine, plants excepted.

The plants found fossil are *Sea-weeds*, and also the first of *land plants*, of the tribes of Lycopods and Ferns.

All the sub-kingdoms of animals were represented, *with the exception of the Vertebrates*. Among *Radiates* there were Corals and Crinoids; among *Mollusks*, representatives of all the several orders; among *Articulates*, the water-divisions, Worms and Crustaceans.

1. **Radiates.**—The Canadian beds, especially the finer *slates* and shales, are remarkable for the great abundance

of very delicate plume-like remains of Radiate life, called *Graptolites*, from the Greek *γράφω*, *I write*.



GRAPTOLITES. — Fig. 195, *Dichograptus Logani*, the central portion of a radiating group of stems with parts of the stems; 196, same, portion of one of the stems, and 196 a, part of stems enlarged; 197, *Diplograptus pristis*; 198, 199, *Phyllograptus typus*; 200, the young of a Graptolite.

A few of the kinds are represented in Figs. 195, 196, 198–200, and one species, from the later part of the Trenton period, in Fig. 197. In the living state there were cells along the notched margin, one for each notch, from which little star-shaped animals extruded themselves. They belong to the tribe of Hydroids, under Acalephs, described on page 184.

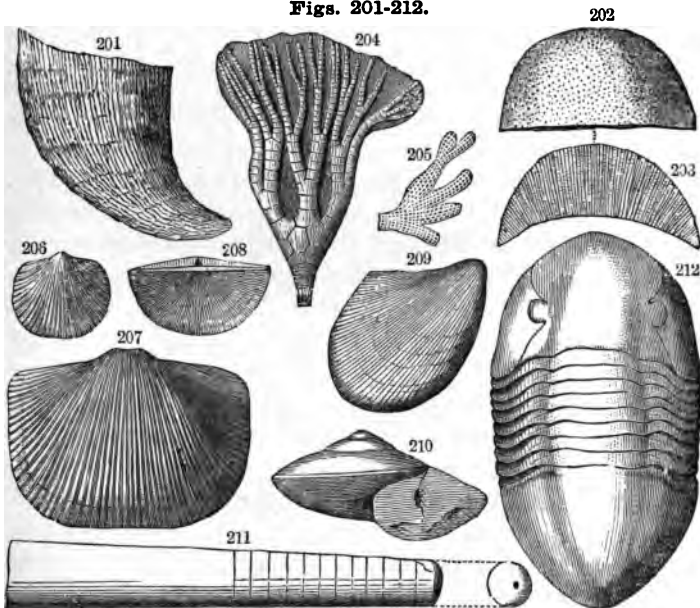
Fig. 201 represents one of the Corals of the Trenton. Its shape is that of a curved cone, a little like a short horn, the small end being the lower. At top, when perfect, the cavity of the coral is divided off by plates radiating from the centre. Such corals are called *Cyathophylloid* corals, from the Greek *κύαθος*, cup, and *φύλλον*, leaf, alluding to the cup full of radiating leaves or plates. When living, the coral occupied the interior of an animal similar to that represented in Fig. 168, or Fig. 169 on page 183.

Another kind of coral, of a hemispherical form, and made up of very fine columns, is represented in Figs. 202, 203, the latter showing the interior appearance. It is called *Chaetetes lycoperdon*. Another, of coarser columns, — each nearly a sixth of an inch in diameter, — is called the *Columnaria alveo-*

lata. In a transverse section the columns are divided off by horizontal partitions. Masses of this coral have been found that weigh each between two and three thousand pounds.

Fig. 204 shows the form of one of the Crinoids, though the stem on which it stood is mostly wanting, and the arms are not entire. The mouth was in the centre above, and the animal was related to the Comatula among star-fishes, from which it differed in being attached to the sea-bottom by means of a jointed stem. There were also true star-fishes in the seas.

Figs. 201-212.



RADIATES OF THE TRENTON PERIOD. — Fig. 201, *Petraia corniculum*; 202, 203, *Chatetes lycoperdon*; 204, *Lecanocrinus elegans*. — **MOLLUSKS**: Fig. 205, *Stictopora acuta*; 206, *Orthis testudinaria*; 207, *Orthis occidentalis*; 208, *Leptæna sericea*; 209 *Ambonychia bellistriata*; 210, *Raphistoma lenticularis*; 211, *Orthoceras junceum*. — **ARTICULATES**: Fig. 212, *Asaphus gigas*.

2. **Mollusks.** — Among *Mollusks* Bryozoans were very common: the fossils are small cellular corals: one is shown in Fig. 205. Brachiopods were still more characteristic of the

period, and occur in vast numbers. Fig. 206 is *Orthis testudinaria*; Fig. 207, *O. occidentalis*; Fig. 208, *Lepæna sericea*. There were also some Lamellibranchs, as Fig. 209, *Ambonychia bellistriata*; and some Gasteropods, as Fig. 210, *Raphistoma lenticularis*. Shells of Cephalopods were especially common under the form of a straight or curved horn with transverse partitions. Fig. 211, *Orthoceras junceum*, represents a small species. One kind had a shell 12 or 15 feet long and nearly a foot in diameter. The word *Orthoceras* is from the Greek *ὀρθός* *straight*, and *κέρας* *horn*.

There were some species also of the genus *Nautilus*.

3. **Articulates.**—Fig. 212 represents one of the large Trilobites of the Trenton rocks, the *Asaphus gigas*,—a species sometimes found a foot long. Another Trilobite is the *Calymene Blumenbachii*, represented in Fig. 148, page 180.

While Trilobites appear to have been the largest and highest life of the Primordial seas, Cephalopods, of the *Orthoceras* family, far exceeded Trilobites in both respects in the Trenton. The larger kinds must have been powerful animals to have borne and wielded a shell 12 or 15 feet long. Although clumsy compared with the fishes of a later age, they emulated the largest of fishes in size, and no doubt also in their voracious habits. Crustaceans, in their highest divisions, as the Crabs, may perhaps be regarded by some as of superior rank to Cephalopods. But Trilobites, of the inferior division of Crustaceans, without proper legs, living a sluggish life in slow movement over the sands or through the shallow waters, or skulking in holes, or attached like limpets to the rocks, were far inferior species to the Cephalopods.

3. General Observations.

1. **Geography.**—The wide continental region covered by the Trenton limestone formation, stretching over the *Appalachian* region on the east, and widely through the *Interior* basin, must have been throughout a clear sea, densely populated over its bottom with Brachiopods, Corals, Crinoids, Trilobites,

and the other life of the era. It may, however, have been a *shallow* sea ; for the corals and beautiful shells of coral reefs live mostly within 100 feet of the surface.

During the later part of the period, or that of the Cincinnati group, the same seas, especially on the north, became more open to sediment, through some change of level or of coast-barriers, and consequently much of the former life disappeared, and other kinds, adapted to impure waters or to muddy bottoms, supplied their places.

2. Disturbances during the Lower Silurian, and at its Close. —

1. Igneous ejections in the Lake Superior district. — During the progress of the Canadian period there were extensive igneous ejections through fractures of the earth's crust in the vicinity of Lake Superior, about Keweenaw Point and elsewhere ; and probably to some extent also over the bottom or area of the lake itself, for this is indicated by the dikes and columnar trap of Isle Royale, an island in the lake. These rocks, which were melted when ejected, now stand in many places in bold bluffs and ridges ; and mixtures of scoria and sand make up some of the conglomerate beds of the region. The sandstones, penetrated by the dikes of trap, and made partly before and partly after the ejection, have a thickness in some places of six or eight thousand feet. The great veins of native copper of the Lake Superior region are part of the results of this period of disturbance. The copper occurs in masses, sheets, strings and grains, all more or less crystalline, and one sheet was 40 feet long and about 200 tons in weight.

2. Emergence of the region of the Green Mountains. — The changes from deep to shallow seas, or partly emerged flats, during the Silurian era, are evidence that changes of level, by gentle movements or oscillations in the earth's crust, were going on throughout it. But after the Lower Silurian had closed there appear to have been greater and more permanent changes. The valley of Lake Champlain and the Hudson, as shown by Logan, probably dates from this time. The Green Mountains were probably then made and became part of the

stable dry land, like the Archæan regions. (See map, page 199.) That they were not dry land before is shown by the Chazy and Trenton limestones in their structure, for these are of marine origin; and that the region was above the water from and after this time is indicated by the fact that the Trenton formations were the latest there formed, and by the still more important observation that near Hudson, in the Hudson River valley, and near Bernardston, in the Connecticut Valley, there are Upper Silurian rocks overlying unconformably the upturned older rocks.

During the progress of the Lower Silurian era a great thickness of rock had been made over the Green Mountain region, — probably 15,000 or 20,000 feet. These beds were laid down, not in a sea 15,000 or 20,000 feet deep until it was full, but in shallow waters over a bottom that was *gradually sinking*, — and so gradually that the rock-material accumulating over it kept it shallow. Then, when the slowly forming trough had reached this depth, the epoch of catastrophe, that is, of mountain-making, began when the beds were displaced and folded, and consolidated or crystallized. Quartzose sandstones were changed to hard quartzite, — the rock of high ridges in Berkshire and Vermont; earthy sandstones were made into mica-schist and gneiss; and common limestones came out white or clouded marbles, now extensively quarried for architectural purposes in Canaan, Connecticut, Berkshire County in Massachusetts, and at Rutland and elsewhere in Vermont. Thus, this northern end of the Appalachian region was the first of it to be made into mountains and become part of the stable land; the rest of it to the south, as well as the central region of Southern New York, was still receiving, for a long era afterward, new formations, and so preparing for another time of mountain-making, — that of the Alleghany range.

Besides this uplifting and upturning in Western New England, there was at the same time, as shown by Safford and Newberry, a bending upward of the Lower Silurian beds along

a region extending southwestward from Lake Erie over Cincinnati through Kentucky, which area was partly an emerged peninsula or island through the rest of Paleozoic time.

In Great Britain and Europe also there were disturbances at the close of the Lower Silurian. The range of Southern Scotland has been referred to this epoch, and so also the Westmoreland Hills, and mountains in North Wales, and hills in Cornwall.

3. **Life.** — There is no evidence that the system of life in its progress during the Lower Silurian had so far advanced as to include a terrestrial animal, or the lowest of Vertebrates. Trilobites held the first position in the Primordial Period, Orthocerata and other Cephalopods in the Trenton. Among Articulates there were neither Myriapods, Spiders, nor Insects as far as discovered; for these are essentially *terrestrial* animals, and the first species of them thus far found are of Devonian age.

Among the *genera* of the Lower Silurian, only five have living species. These are *Lingula*, *Discina*, *Rhynchonella*, and *Crania* among Brachiopods, and *Nautilus* among Cephalopods. The *Lingulæ* of the Primordial are referred to another genus; but true species of the genus *Lingula* are reported from the Trenton. These genera of long lineage thus reach through all time from the Lower Silurian onward. All other genera disappear, — some at the close of the Primordial, others at that of the Canadian or Trenton period, and some at the termination of subordinate epochs within these periods.

The extermination of species took place at intervals through the periods, as well as at their close; though those at the latter were most universal. With the changes from one stratum to another there were disappearances of some species, and with the changes from one formation to another still larger proportions became extinct. No Primordial species are known to occur in the Canadian period; very few of the species of the Canadian period survive into the Trenton; and very many of those of the early part of the Trenton did

not exist in the later part. Thus life and death were in progress together, species being removed, and other species appearing as time moved on.

3. Upper Silurian Era.

1. Subdivisions.

The Upper Silurian era in North America includes four periods: the NIAGARA, the SALINA, the LOWER HELDERBERG, and the ORISKANY. The name of the *first* is from the Niagara River, along which the rocks are displayed; that of the *second*, from Salina in Central New York, the beds being the salt-bearing rocks of that part of the State; that of the *third*, from the Helderberg Mountains, south of Albany, where the lower rocks are of this period; that of the *fourth*, from Oriskany, a place in Central New York, northwest of Utica.

2. Rocks: Kinds and Distribution.

The rocks of the *Niagara* period are: 1. A conglomerate and grit-rock called the *Oneida conglomerate*, which extends from Central New York southward along the Appalachian region, having a thickness of 700 feet in some parts of Pennsylvania; together with shaly sandstones of the *Medina group*, which spread westward from Central New York through Michigan, and also southward along the Appalachian region, being 1,500 feet thick in Pennsylvania; 2. Hard sandstones, or flags and shales of the *Clinton group*, having nearly the same distribution as the *Medina* formation, though a little more widely spread in the west, and about 2,000 feet thick in Pennsylvania; 3. The *Niagara group*, occurring in Western New York, and extending widely over both the Appalachian and Interior Continental regions: it consists, at Niagara, of shales below and thick limestone above; mainly of limestone in the Interior region; and of clayey sandstone or shales in the Appalachian region, where it has a thickness of 1,500 feet or more. The Niagara is one of the great limestone

formations of the continent, existing also in the Arctic regions.

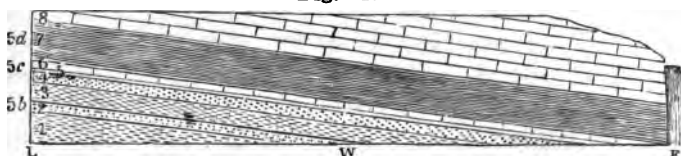
Ripple-marks and mud-cracks are very common in the Medina formation. The example of rill-marks figured on page 46 is from its strata in Western New York.

The *Salina* rocks are fragile, clayey sandstones, marlytes, and shales, usually reddish in color, and including a little limestone. They occur in New York and sparingly to the westward, being thickest (700 to 1,000 feet thick) in Onondaga County, New York.

The salt of Salina and Syracuse, in Central New York, is obtained from wells of salt water 150 feet and upward in depth, which are borings into these saliferous rocks. From 35 to 45 gallons of the water afford a bushel of salt, while of sea-water it takes 350 gallons for the same amount. No solid salt is there found; but farther west, near Wyoming and Warsaw, N. Y., a bed, 50 to 100 feet thick, occurs at a depth of 1,200 to 1,500 feet; and near Goderich, in Canada, at a depth of about 1,000 feet, a bed 14 to 40 feet thick. Gypsum is common in some of the beds.

The *Lower Helderberg* group consists mainly of limestones, and is the second limestone formation of the Upper Silurian. The formation is well developed in the State of New York and along the Appalachian region to the south; it also occurs in Ohio, Indiana, Southern Illinois, and Tennessee; also

Fig. 213.



Section along the Niagara, from the Falls to Lewiston Heights.

along the Connecticut Valley, in Northern Maine, and in New Brunswick and Nova Scotia.

The section, Fig. 213, represents the rocks on the Niagara

River at and below the Falls. The Falls are at F; the whirlpool, three miles below, at W; and the Lewiston Heights, which front Lake Ontario, at L. Nos. 1, 2, 3, 4 are different sandstone strata belonging to the Medina group; 5, shale, and 6, limestone, to the Clinton group; 7, shale, and 8, limestone, to the Niagara group. The next section (Fig. 214),

Fig. 214.



Section of the Salina and underlying strata, from north to south, south of Lake Ontario.

from the region south of the eastern part of Lake Ontario, consists as follows: 5 *b*, Medina group, 5 *c*, Clinton group, 5 *d*, Niagara group (shale and limestone), 6, Salina beds. (Hall.)

The Oriskany beds are mostly rough sandstones. The formation extends from Oriskany, New York, southward along the Appalachian region through Pennsylvania, Maryland, and Virginia, where it is several hundred feet thick. It occurs also in Northern Maine, and at Gaspé on the Gulf of St. Lawrence, where the rock is partly limestone.

In Great Britain the Upper Silurian rocks are first sandstones and shales, called, where occurring in South Wales, *Llandovery beds*, and corresponding to the Medina and Clinton groups. Above these there is the *Wenlock* limestone group, consisting of limestone and some shale (and including, in the upper portion, the *Dudley* limestone). These rocks occur as surface-rocks near the borders of Wales and England. Next comes the *Ludlow group*, of the age of the Lower Helderberg and Oriskany beds.

In Scandinavia the Gothland limestone is the equivalent of the Niagara.

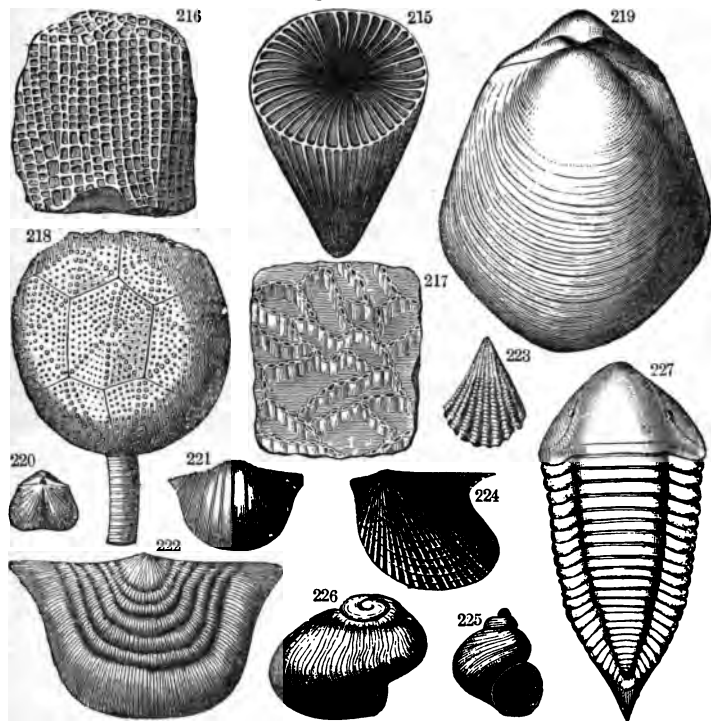
3. Life.

The limestone strata and most of the other beds of the Niagara group are full of fossils; and so also are the rocks of

the Lower Helderberg period, and of the Wenlock and Ludlow formations in Great Britain. Nearly all of the Salina formation is destitute of them.

The life of the era was the same in general features as that of the latter half of the Lower Silurian, though mostly different in species.

Figs. 215-227.



RADIATES : Fig. 215, *Zaphrentis bilateralis*, Clinton group ; 216, *Favosites Niagarensis*, Niagara group ; 217, *Halysites catenulata*, id. ; 218, *Caryocrinus ornatus*, id. — **MOLLUSKS** : Fig. 219, *Pentamerus oblongus*, Clinton gr. ; 220, *Orthis varica* ($\times 2$), Niagara gr., and Dudley limestone ; 221, *Leptæna transversalis*, id. ; 222, *Strophomena rhomboidalis*, id. ; 223, *Rhynchotreta cuneata*, U. S. and Great Britain, id. ; 224, *Pterinea emacerrata*, Niagara gr. ; 225, *Cyclonema cancellata*, Clinton gr. ; 226, *Platyceras, angulatum*, Niagara gr. — **ARTICULATES** : Fig. 227, *Homalonotus delphinocephalus*, id.

The only plants yet found in the Lower Helderberg and underlying beds are *Algæ*, or Sea-weeds ; but in the Oriskany

beds of Gaspé are found remains of true terrestrial species, related to the Lycopods or modern Ground-pine. They were about as large as the common *Lycopodium dendroideum* of the present day. (See page 188.) Similar remains of plants have been found also in the Upper Ludlow beds of Great Britain.

In the Animal Kingdom the sub-kingdom of *Radiates* was represented most prominently by Corals and Crinoids; that of *Mollusks*, by species of all the grand divisions, among which the Brachiopod and Orthoceras tribes were the most characteristic, and especially the Brachiopod, whose shells far outnumber those of all other Mollusks; that of *Articulates*, by Worms, Ostracoids, and Trilobites; and, before the close of the era, by the new form of Crustaceans represented in Fig. 235.

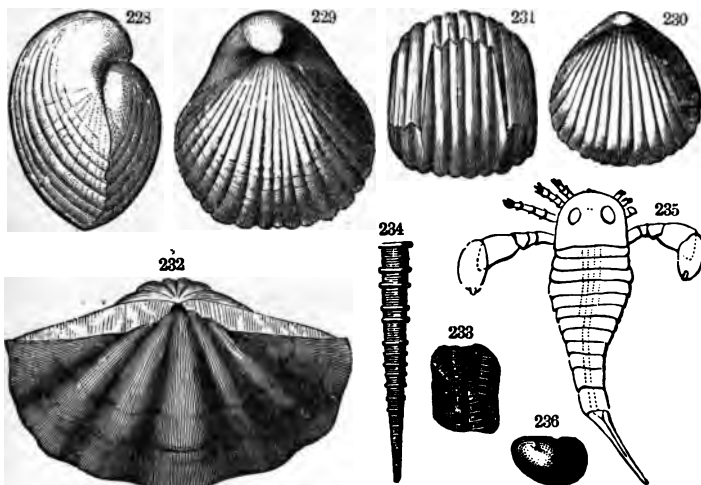
1. **Radiates.** — Fig. 215 is a polyp-coral of the *Cyathophylloid* tribe, showing the radiating plates of the interior; Fig. 216, a species of *Favosites*, a genus in which the corals have a columnar structure (somewhat honeycomb-like, whence the name from the Latin *favus*, *honeycomb*), and horizontal partitions subdivide the cells within; Fig. 217, *Halysites catenulata*, called *chain-coral*; Fig. 218, a Crinoid, *Caryocrinus ornatus*, the arms at the summit broken off; Fig. 164, page 183, another Crinoid of the family of *Cystideans*, from the Niagara group; Fig. 162, page 183, a star-fish, also from the Niagara group.

2. **Mollusks.** — Figs. 219 to 223, different Brachiopods of the Niagara period; Figs. 228 to 234, other species characteristic of the Lower Helderberg period; Figs. 225, 226, Gastropods; and Fig. 224, a Lamellibranch of the Niagara period. Fig. 233 represents small slender tubular cones, called *Tentaculites*, which almost make up the mass of some layers in the Lower Helderberg; the form of one enlarged is shown in Fig. 234; they are regarded as the shells of Pteropods.

3. **Articulates.** — Fig. 227 is a reduced figure of a common Trilobite of the Niagara group, a species of *Homalonotus*, often having a length of 8 or 10 inches. Fig. 235 represents *Eurypterus remipes*, a species of a family of Crustaceans, occurring first in the Utica shale; it is sometimes nearly

a foot long. Species of the same family occur in Great Britain in the Ludlow beds, and one of them is supposed, from the fragments found, to have been 6 or 8 feet long, far surpassing any Crustacean now living; Fig. 236, an *Ostracoid* Crustacean, the *Leperditia alta*, of unusually large size for the family, modern Ostracoids seldom exceeding a twelfth of an inch in length.

Figs 228-236



MOLLUSKS: Figs. 228, 229, *Pentamerus galeatus*; 230, 231, *Rhynchonella ventricosa*; 232, *Spirifer macroleptus*; 233, *Tentaculites irregularis*; 234, *id.* enlarged. — **ARTICULATES:** Fig. 235, *Eurypterus renipes*, a small specimen; 236, *Leperditia alta*. Species all from the Lower Helderberg group.

4. **Vertebrates.** — The first remains of Vertebrates yet discovered occur in the Upper Silurian. They are of fishes, and have been found in the Ludlow beds of Great Britain. They are teeth, scales, and other relics, chiefly of shark-like species. The kinds are further described under the Devonian.

4. General Observations.

1. **Geography.** — On the map, page 195, the areas over which the Silurian formations are surface-rocks are distinguished by

being *horizontally* lined. It is observed that they spread southward from the northern Archæan area, and indicate an extension in that direction of the growing continent.

South of the Silurian area commences the Devonian, which is *vertically* lined; and the limit between them shows approximately the course of the sea-shore at the close of the Silurian age. It is seen that more than half of New York, and nearly all of Canada and Wisconsin, had by that time become part of the dry land; but a broad bay covered the Michigan region to the northern point of Lake Michigan, for here Devonian rocks, and to some extent Carboniferous, were afterward formed. The Archæan dry land, the nucleus of the continent, had also received additions in a similar manner on its eastern and western sides, through British America.*

But, with all the increase, the amount of dry land in North America was still small. Europe is proved by similar evidence to have had much submerged land. The surface of the earth was a surface of great waters, with the continents only in embryo,—one large area and some islands representing that of North America, and an archipelago that of Europe. The emerged land, moreover, was most extensive in the higher latitudes. The rivers of a world so small in its lands must also have been small. The lands, too, according to present evidence, had no green sward over the rocks, except during the closing part of the Silurian age.

The succession of Upper Silurian formations is as follows :

1. The Medina sandstone having at base the coarse grit called Oneida conglomerate, occurring of great thickness along the Appalachian region, and reaching north to Central New York,

* On the map referred to, page 195, lines of the Silurian and Devonian are seen to extend from the Hudson River southwestward along the Appalachian region. But the outcrop of the Silurian, here represented, is not evidence that there was a strip of dry land along this region from the close of the Silurian era, because there is proof that these Appalachian outcrops are a consequence of the uplift of the Alleghany Mountains, an event of much later date. (Page 277.)

and, besides, spreading westward beyond the limits of that State; 2. The Clinton group of flags and shales, having the same Appalachian extension and great thickness, but spreading on the north much farther westward, even to the Mississippi; 3. The Niagara group, covering the Appalachian region deeply with sandstones and shales, and New York with shales and limestones, and spreading as a great limestone formation through the larger part of the Interior region; then (4) the limited Salina salt-bearing marlytes of New York, extending west through Canada, and over part of the Appalachian region southwest; then (5) another limestone, but impure, spreading over New York State and the Appalachian region, and also some of the States west; and also occurring in the Connecticut Valley and over Maine to the Gulf of St. Lawrence. These facts teach that geographical changes took place from time to time, in the course of the era, corresponding to these several changes in the formations. The clear continental seas of the Trenton period were succeeded by conditions fitted to produce the several arenaceous and argillaceous formations, of varying limits, which followed; but clear waters returned again at the epoch of the Niagara group, when corals, crinoids, and shells covered the bottom of the continental sea and made the Niagara limestone formation. But these seas in the Niagara epoch were less extended than those of the Trenton; for the Appalachian region, instead of being part of the pure sea and making limestones, was receiving great depositions of sand and clay, as if it were at the time a broad reef, or bank, bordering the Atlantic Ocean.

The Niagara epoch of limestone-making was followed by the Salina or saliferous period. Since the beds are (1) clays and clayey sands, (2) are almost wholly without fossils, and (3) afford salt, it may be inferred that Central New York was at the time a great salt marsh, mostly shut off from the sea. Over such an area the waters would at times have become too salt to support life, owing to partial evaporation under the hot sun, and too fresh at other times, from the rains. More-

over, muddy deposits would have been formed ; for they are now common in salt marshes wherever there is, as there was then, no covering of vegetation, and the salt waters would naturally have yielded salt on evaporation in the drier seasons. Through an occasional ingress of the sea, the salt waters might have been resupplied for further evaporation.

There is direct testimony as to the condition of the land and shallowness of the waters in the regions where many of the rocks were in progress ; for ripple-marks and mud-cracks are common in some layers, and are positive evidence that the sands and earth that are now the solid rock were then the loose sands of beaches, sand-flats, or sea-bottoms, or the mud of a salt marsh. Such little markings, therefore, remove all doubt as to the condition of Central New York in the Salina period.

Similar markings indicate, also, the precise condition of the region of the Medina sandstone, showing that there were sand-flats, sea-beaches, and muddy bottoms open to the inflowing sea. Where the *rill-marks* were made (Fig. 24, page 46) the sands of the spot were those of a gently sloping flat or beach ; the waters swept lightly over the sands, dropping here and there a stray shell (as the *Lingula cuneata*) or a pebble, which became partly buried ; and then, as they retreated, they made a tiny plunge over the little obstacle and furrowed out the loose sand below it. The fineness of the sand, lightness of the shells, and smallness of the furrows are proof that the movements were light.

The great thickness of the several formations of the Upper Silurian along the Appalachian region leads to many interesting conclusions. It has been stated (page 217) that the Appalachian formations of the earlier Silurian were equally remarkable for their great thickness. The Appalachian region, from the Primordial era onward, was, hence, in strong contrast with the Interior Continental region, where the series of coterminous beds are hardly *one tenth* as thick. Taking this into connection with another fact, that very

many of the strata among the thousands of feet of Silurian formations in the Appalachian region contain those evidences of shallow water and mud-flat or sand-flat origin above explained, there is full proof that in the Silurian era the region was for the most part, as already suggested, a vast sand-reef, ever increasing by new accumulations under the action of the waves and currents of the ocean. It was much of the time a great barrier-reef lying between the open ocean and the Interior Continental sea; and under its lee, this inner sea, opening southward through the area of the Mexican Gulf, was often in the best condition for the growth of the Shells, Corals, and Crinoids of which the great limestones were made.

While the Appalachian region was alike in its general condition through the earlier and later Silurian, the limits of the formations in progress during these two eras were somewhat different, as explained on page 217. The part of the Appalachian region which participated, during the Upper Silurian era, in the great changes connected with the formation of rocks, extended northward from Pennsylvania into New York, and not along the Green Mountains; the rocks in the State of New York have great thickness for some distance beyond the Pennsylvania border, but thin out about the centre.

2. *Life*. — In the Upper Silurian the highest species of the seas and of the world continued for a while to be Mollusks, of the order of Cephalopods. But before its close there were fishes in the waters, and *Vertebrates* ever afterward existed as the highest species. Corals and Crinoids were the only kinds of life that had the semblance of flowers. These flower-animals foreshadowed the flowers of the vegetable kingdom for ages before any of the latter existed. The Lycopods of the later part of the Upper Silurian were *flowerless* plants, like the Ferns.

Up to 1872, over 10,000 species of Silurian animals — ranging from Sponges to Fishes — had been made known through the study of fossils.

II. AGE OF FISHES, or DEVONIAN AGE

I. Subdivisions.

The Devonian formation was so named by Sedgwick and Murchison, from Devonshire, England, where it occurs.

The Age may be divided into two eras, — an *earlier* and a *later*, or that of the *lower* and that of the *upper* formations. The Lower Devonian includes the CORNIFEROUS period; the Upper Devonian, the HAMILTON, CHEMUNG, and CATSKILL periods.

2. Rocks: Kinds and Distribution.

1. **Earlier and Later Eras.** — The Lower Devonian is remarkable for a great limestone formation, which spread from New York over a large part of the Interior region, and nearly equalled the Trenton in extent; while the Upper includes very little limestone, the rocks being mainly sandstones, shales, and conglomerates.

2. **Corniferous Period.** — The lowest rocks of this period are fragmental beds, called the *Cauda-Galli grit* and the *Schoharie grit*, having their distribution along the Appalachian region, commencing in Central and Eastern New York and extending southwestward.

Next follows the great *Corniferous limestone*, the lower part of which is sometimes called the *Onondaga limestone*, and the whole often the *Upper Helderberg group*. It stretches from Eastern New York westward to the States beyond the Mississippi.

The name *Corniferous* (derived from the Latin *cornu*, *horn*) was given it by Eaton, from its frequently containing a kind of flint called *hornstone*. This hornstone differs from true flint in being less tough, or more splintery in fracture, though it is like it in hardness and in consisting wholly of silica.

The limestone is in many places literally an ancient coral reef. It contains corals in vast numbers and of great variety;

and in some places, as at the Falls on the Ohio, near Louisville, Kentucky, the resemblance to a modern reef is perfect. Some of the coral masses at that place are 5 or 6 feet in diameter; and single polyps of the Cyathophylloid corals had in some species a diameter of 2 and 3 inches, and in one, of 6 or 7 inches.

The same reef-rock occurs near Lake Memphremagog on the borders of Vermont and Canada, and also at Littleton, New Hampshire; but the corals have in these places been partly obliterated by metamorphism.

3. Hamilton Period.—The Hamilton formation consists in New York of sandstones and shales, with a few thin layers of limestone. It consists of three parts, corresponding to three epochs: the lower part is called the *Marcellus shale*; the middle, the *Hamilton beds*; and the upper, the *Genesee shale*. It has its greatest thickness along the Appalachians. From New York it spreads westward, where it is in part calcareous, and forms the upper part of the “cliff” limestone. It includes a stratum of *black shale* (supposed to be of the epoch of the Genesee shale), 100 to 350 feet thick, which yields in some places 15 to 20 per cent of mineral oil. The formation occurs also in Eastern Maine, New Brunswick, and at Gaspé, on the Gulf of St. Lawrence.

The Hamilton beds afford an excellent flagging-stone in Central New York, and on the Hudson River, near Kingston, Saugerties, Coxsackie, and elsewhere, which is extensively quarried and exported to other States.

4. Chemung Period.—The Chemung beds are mainly sandstones, or shaly sandstones, with some conglomerate. They spread over a large part of Southern and Western New York, having great thickness in the Catskill Mountains. A shale of the period in Northern Ohio is called the *Erie shale*.

The formation along the Appalachians is 5,000 feet thick. It thins out to the west of New York, in Ohio, and Michigan.

In the following section, taken on a north-and-south line south of Lake Ontario, No. 6 represents the beds of the

Salina period; overlaid by 7, the Lower Helderberg limestone; 9, the Corniferous, or Upper Helderberg limestone; 10, *a*, *b*, *c*, the Hamilton beds; and 11, the Chemung group.

Fig. 237.



Section of Devonian formations south of Lake Ontario.

5. Catskill Period. — The rocks are sandstones, shaly sandstones, and shales; they occur in Eastern New York, and are 2,000 to 3,000 feet thick in the Catskill Mountains. They also extend southwestward along the Appalachians, being 5,000 to 6,000 feet thick in Pennsylvania.

In Great Britain the Devonian rocks include the *Old Red Sandstone*, the prevailing rock of the age in Wales and Scotland. The thickness in some places is 8,000 to 10,000 feet. This formation, besides sandstone, includes marlytes of red and other colors, and some limestone. The distribution in Great Britain is shown on the map, page 244. In Germany, in the Rhenish provinces, there is a coral limestone very similar to that of North America.

3. Life.

1. General Characteristics.

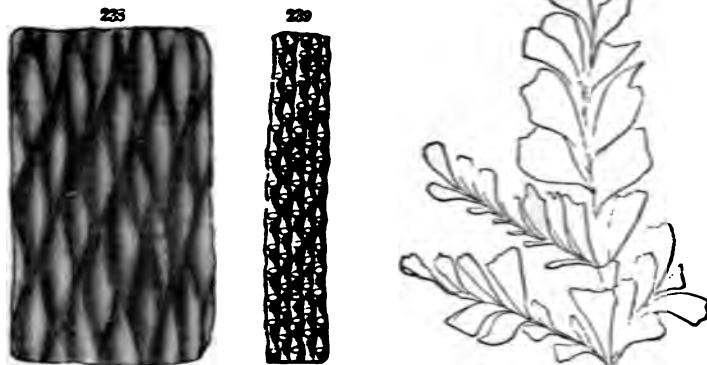
The Devonian of North America was characterized by forests and an abundance of insects over the land, and by fishes of many kinds in the waters.

2. Plants.

Figs. 238–240 represent portions of some of the plants. Fig. 240 is a fragment of a *Fern*, and Figs. 238, 239, portions of the trees, of the age. The scars or prominences over the surface are the bases of the fallen leaves; a dried branch of a Norway spruce, stripped of its leaves, looks closely like Fig. 239. By referring to page 186, it will there be seen that

among the Cryptogams there is one order, the highest, or that of *Acrogens*, in which the plants have upward growth

Figs. 238-240



PLANTS. — Fig. 238, *Lepidodendron primævum*, from the Hamilton group; 239, *Sigillaria Hallii*, *ibid.*; 240, *Noeggerathia Halliana*, from the Chemung group.

like ordinary trees, and the tissues are partly vascular: it is the one containing the *Ferns*, *Lycopods*, and *Equiseta* or *Horse-tails*. The most ancient of land plants belong, to a great extent, to this order, — the *highest of Cryptogams*, and were of the three kinds just mentioned. Another portion are related to the lowest order of *flower-bearing* plants or *Phenogams*, called *Gymnosperms* (see page 188).

The groups represented under these divisions are the following:—

I. Flowerless Plants, or Cryptogams, Order of Acrogens.

1. **Fern Tribe.** — The species have a general resemblance to the ferns or brakes of the present time.

2. **Lycopods**, or plants related to the *Ground-Pine*. — The existing plants of this tribe are slender species, seldom over 4 or 5 feet high: some of the ancient kinds were of the size of

forest-trees. These ancient species belong mostly to the *Lepidodendron* family, in which the scars are contiguous and are arranged in quincunx order, that is, alternate in adjoining rows, as shown in Fig. 238. The name *Lepidodendron* is from the Greek *λεπίς*, *scale*, and *δένδρον*, *tree*, and alludes to the scar-covered trunk, which looks something in surface like a scale-covered reptile. The Ground-Pine of modern woods, although flowerless like the fern, has leaves very similar to those of the Spruce or Cedar (Conifers); and this type of plants is intermediate in some respects between the Acrogens and Gymnosperms (Conifers).

The *Sigillarids*, another family in this tribe, included trees of moderate height, with stout, sparingly branched trunks, bearing long linear leaves much like those of the *Lepidodendrids*; but the scars on the exterior are mostly in *parallel vertical* lines, as in Fig. 239, and Fig. 283, page 251, and not like those of the *Lepidodendra*. The name is from the Latin *sigillum*, *a seal*, in allusion to the scars.

3. Equisetum, or Horse-tail Tribe.—The *Equiseta* of modern wet woods are slender, hollow, jointed rushes, called sometimes *scouring-rushes*. They often have a circle of slender leaf-like appendages at each joint. The *Calamites* or *Tree-rushes*, which are referred to this tribe, are peculiar to the ancient world, none having existed since the Mesozoic. They had jointed striated stems like the *Equiseta*, and otherwise resembled them. But they were often a score of feet or more in height, and over 6 inches in diameter. Some of them had hollow stems like the *Equiseta*; others had the interior of the stems partially woody, and these were intermediate in some respects between the *Equiseta* and the Gymnosperms. Fig. 286, page 251, represents a portion of one of these plants.

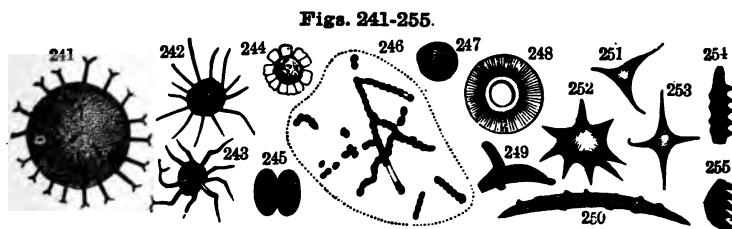
II. Flowering Plants, or Phenogams, of the Order of Gymnosperms.

Conifers.—The species are related to the common Pines and Spruces, or more nearly to the Araucanian Pines of Aus-

tralia and South America. The fossils are merely portions of the trunk or branches.

Conifers, Ferns, and Lepidodendrids have also been reported from some of the Devonian beds of Britain and Europe.

The hornstone, which is massive quartz, or silica, develops, under the microscope, the fact that it was probably made from the siliceous remains of plants and animals. Figs. 241 to 255 represent some of the species which have been detected by Dr. M. C. White in specimens from New York and elsewhere. Figs. 241 to 247 are microscopic plants, related to



Microscopic Organisms from the Hornstone.

the *Desmids* ; Fig. 248 is another kind, called a *Diatom*, a kind which forms siliceous shells, and which is probably one of the sources of the silica of which the hornstone was made. (See, on Diatoms and Desmids, pages 68 and 187.) Figs. 249, 250 are spicules of Sponges, also siliceous, and another of the sources of the silica. Figs. 251, 252 are probably also sponge-spicules. Figs. 254, 255 are fragments of the teeth of some Gasteropod Mollusk. The last is from a hornstone of the Trenton period which was found to afford the same evidences of organic origin.

3. Animals.

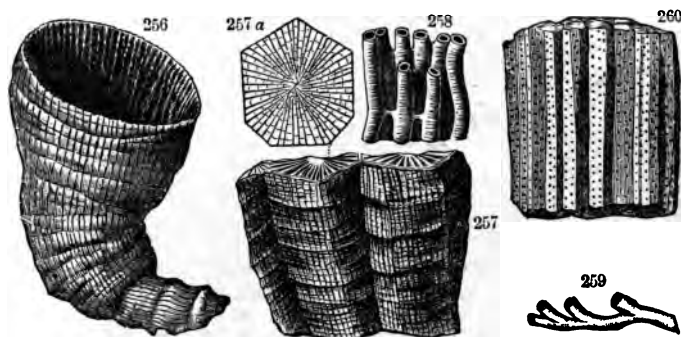
The early Devonian was the coral period of the ancient world. In no age before or since, not even the present, have coral reefs of greater extent been formed.

Among Mollusks, Brachiopods were still the prevailing kinds, though ordinary Bivalves or Lamellibranchs, and

Univalves or Gasteropods, were more abundant than in the Silurian. A new type of Cephalopods commenced in the Middle Devonian. Hitherto, the partitions or septa in the shells, straight or coiled, were flat or simply concave; but in the new genus *Goniatites* the margin of the plate has one or more deep flexures, one of the flexures or pockets being at the middle of the back of the shell. The name is from the Greek γόνυ, *knee* or *angle*. Fig. 266 (page 236) represents one of the species, and Fig. 266 *a* shows some of the flexures along the back of the shell.

Among Articulates there were Worms and Crustaceans, as in earlier time, and the most common Crustaceans were *Trilobites*. Besides these there were the first of Insects, the wings of some species having been reported from the Devonian of New Brunswick.

Figs. 256-230.



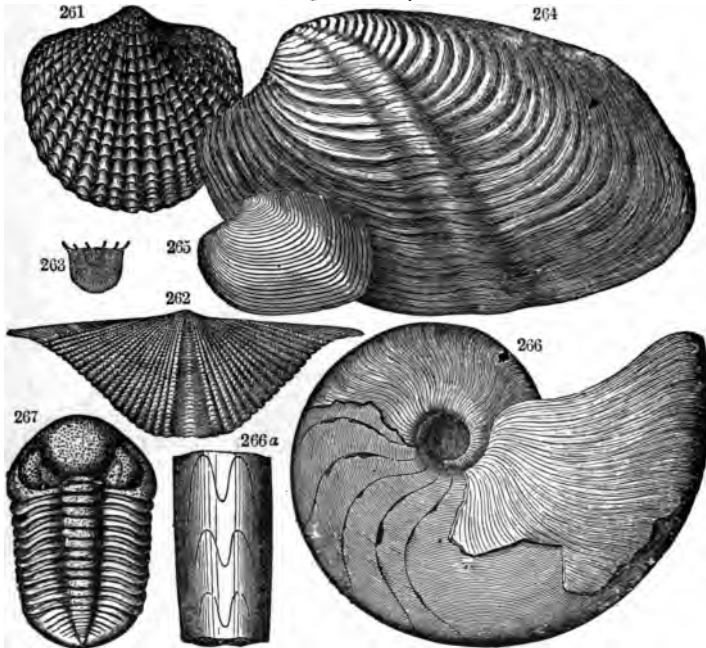
RADIATES. — Fig. 256, *Zaphrentis Rafinesquii*; 257, 257 *a*, *Cyathophyllum rugosum*; 258, *Syringopora Maclurii*; 259, *Aulopora cornuta*; 260, *Favosites Goldfussi*; all of the Corniferous period.

1. Radiates. — Fig. 256, one of the Cyathophylloid corals, *Zaphrentis Rafinesquii*; Fig. 257, another, *Cyathophyllum rugosum*, both from the Falls of the Ohio, and the latter forming very large masses. Fig. 257 *a* is a top view of the cells in Fig. 257. Fig. 260, a *Favosites* from the same locality, showing well the columnar structure characterizing the genus;

the species *F. Goldfussi* occurs both in America and Europe. Figs. 258, 259 are small corals from Canada West.

2. Mollusks.—Figs. 261 to 267, Brachiopods from the Hamilton beds; Figs. 264, 265, Lamellibranchs, from the

Figs. 261-267.



MOLLUSKS: Fig. 261, *Atrypa spinosa*; 262, *Spirifer mucronatus*; 263, *Chonetes setigera*; 264, *Grammysia bisulcata*; 265, *Microdon bellistriatus*; 266, 266 a, *Goniatites Marcellensis*: all from the Hamilton group. — **ARTICULATES:** Fig. 267, *Phacops bufo*, from the Hamilton group.

same; Fig. 266, the Cephalopod, *Goniatites Marcellensis*, from the same; Fig. 266 a, a view of the back, showing the flexures in the partitions, this species having but one flexure or pocket.

3. Articulates.—Fig. 267, the Trilobite, *Phacops bufo*, one of the common species of the Hamilton. The earliest remains of Insects yet discovered have been found in beds

supposed to be of the Hamilton era, at St. John's, New Brunswick. A wing of a gigantic species of May-fly is represented in Fig. 268.

4. Vertebrates.—The fishes of the Devonian belong to three orders: 1. the *Selachians*, or *Sharks*; 2. the *Ganoids*; and 3. the *Placoderms*. The *Placoderms* are represented in Figs. 269, 270. The name, from the Greek, alludes to the plates that cover the body much like those of a turtle.

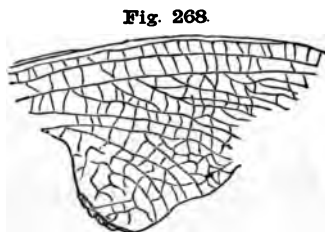
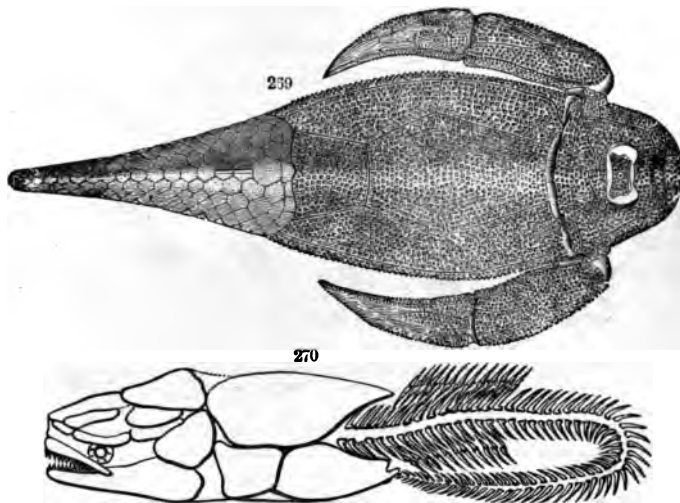


Fig. 268.

Platephemera antiqua.

Some of the *Ganoids* are shown in Figs. 271–276. The

Figs. 269, 270.

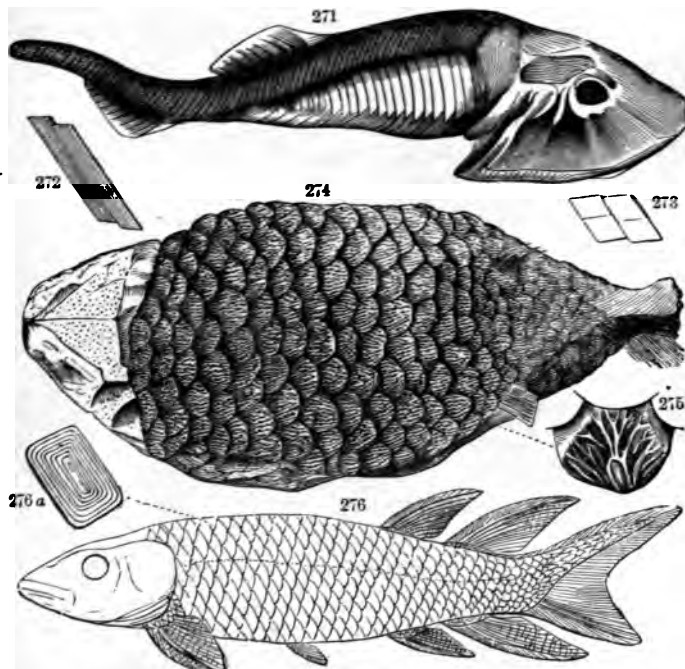


VERTEBRATES.—Fig. 269, *Pterichthys Milleri* ($\times \frac{1}{2}$); 270, *Coccoosteus decipiens* ($\times \frac{1}{2}$).

Ganoids are related to the Gar-pike of some modern lakes and rivers, a kind of fish now rarely met with. They have bony, shining scales, and to this the name, from *γάνος*, *shining*, alludes. As remarked by Agassiz, they have several

characters that ally them to Reptiles; that is, (1) they have the power of moving the head at the articulation between the head and the body, the articulation being made by means of a convex and concave surface; (2) the air-bladder, which answers to the lung of higher animals, has a cellular or lung-

Figs. 271-276



GANOIDS. — Fig. 271, *Cephalaspis Lyellii* ($\times \frac{1}{2}$); 272, 273, scales of same; 274, *Holoptychius* ($\times \frac{1}{2}$); 275, scale of same; 276, *Dipterus macrolepidotus* ($\times \frac{1}{2}$); 276 a, scale of same.

like structure, thus approximating the species to air-breathers; (3) the teeth have in general a structure like that of the early Amphibians. These early species had the tail *vertebrated* (or *heterocercal*), as illustrated in Fig. 276. Fig. 271 represents the *Cephalaspis*, having a flat and broad plate-covered head, with rhombic scales over the body: Fig. 273 shows the

form of some of the scales. Fig. 276 is a species of *Dipterus*, covered with rhombic scales, put on, as in the preceding, much as tiles are arranged on a roof: Fig. 276 *a* is one of the scales, natural size. Fig. 274 represents another type of Ganoids, having the scales rounded (as shown in Fig. 275) and set on more like shingles; it is a *Holoptychius*.

A gigantic Placoderm from Ohio, called *Dinichthys* by Newberry, had a head four feet wide, with dentate lower jaws twenty inches long. It was related to the *Coccosteus*, and also, according to its describer, to the modern *Lepidosiren*.

The *Selachians*, or sharks, belong in part to the family of *Cestracions* (pages 178, 179), or that in which the mouth has a pavement of broad bony pieces for grinding. Others had regular teeth, somewhat like those of ordinary sharks; in one

Fig. 277.



Fin-spine of a Shark ($\times \frac{1}{2}$).

group (the *Hybodonts*) the teeth had prominent points (Figs. 136, 137, page 178), and in another they were of a broad triangular shape. There were species as large as the largest of modern time. Fig. 277 represents a fin-spine of a shark *two thirds* its actual size, from the Corniferous beds of New York.

4. General Observations.

1. **Geography.** — During the Silurian, there had been a gradual gain of dry land on the north, extending the Archæan continent (page 199) southward. This gain continued through the Devonian, so that the formations of the next age, the Carboniferous, extend only a short distance north of the southern boundary of New York. The sea-shore was thus being set farther and farther southward with the progressing periods.

The formations have their greatest thickness along the Appalachian region, as in the Silurian age. And both this fact

and their successions lead to similar general conclusions to those stated on page 228.

2. **Life.** — The great feature of the Devonian age is the occurrence of forests of Acrogens and Conifers ; of Insects and Myriapods, among terrestrial Articulates ; and of great Sharks and Gars in the seas, as representatives of Vertebrates. No Mosses are known to have existed as intermediate species between Sea-weeds and the earliest Lycopods and Ferns.

With regard to Fishes, the earliest species belong to the two high groups of the class, — the Sharks and the Ganoids ; the Ganoids being a type that is partly Reptilian. The rocks have afforded no evidence of any links between the Mollusk, Worm, or Trilobite and these fishes.

III. CARBONIFEROUS AGE, or AGE OF COAL PLANTS.

I. General Characteristics: Subdivisions.

The Carboniferous age was remarkable, in general, for —

1. A low elevation of the continents above the sea-level through long eras alternating with small submergences of the same.

2. Extensive marshy or fresh-water areas over large portions of these low continents.

3. Luxuriant vegetation, covering the land with forests and jungles.

4. Scorpions, true Spiders, Centipedes, Insects, over the land, and Amphibians and other Reptiles over the marshes and in the seas.

But, while having these as its main characteristics, it was not an age of continued verdure. There was, first, a long period — the *Subcarboniferous* — in which the land was largely beneath the sea ; for limestone, full of marine fossils, is the prevailing rock, and there are but few, and mostly thin coal-beds in the sandstones and shales. This period was followed by the *Carboniferous*, or that of the true Coal-measures.

Yet even in this middle period of the age there were alternations of submerged with emerged continents, long eras of dry and marshy lands luxuriantly overgrown with shrubbery and forest-trees intervening between other long eras of great barren continental seas. Then there was a closing period, — the *Permian*, — in which the ocean prevailed again, though with contracted limits; for the rocks are mainly of marine origin.

The Carboniferous period and age were so named from the fact that the great coal-beds of the world originated mainly during their progress. The term *Permian* was given to the rocks of the third period by Murchison, De Verneuil, and Keyserling, from a region of Permian rocks in Russia, the ancient kingdom of Permia, now divided into the governments of Perm, Viatka, Kasan, Orenberg, etc.

2. Distribution of Carboniferous Rocks.

The Carboniferous areas on the map of the United States, page 153, are the dark areas; the black cross-lined with white being the *Subcarboniferous*; the pure black, the *Carboniferous*; the black dotted with white, the *Permian*. The last occur only west of the Mississippi.

The following are the positions of the several great coal areas in North America:—

I. EASTERN BORDER REGION. — 1. The *Rhode Island* area, extending from Newport in Rhode Island northward into Massachusetts.

2. The *Nova Scotia and New Brunswick* area.

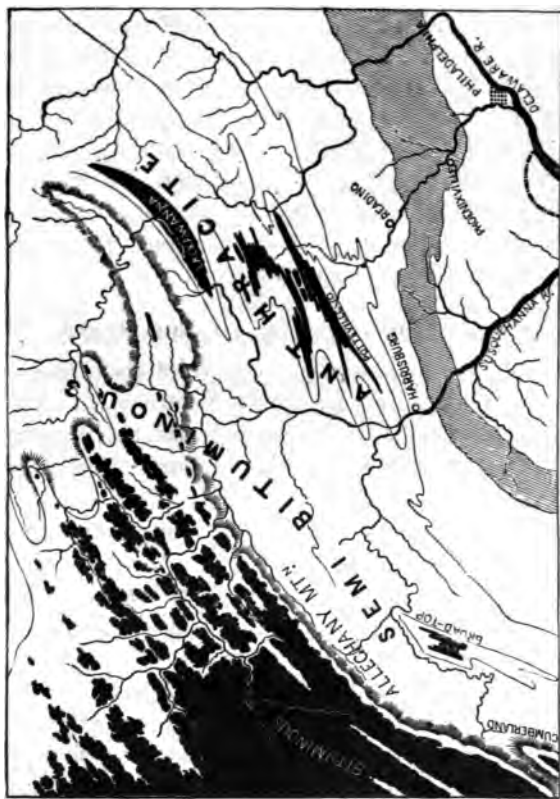
II. ALLEGHANY and INTERIOR REGIONS. — 1. The great *Alleghany* area, extending from the southern borders of New York and Ohio southwestward to Alabama, covering the larger part of Pennsylvania, half of Ohio, part of Kentucky and Tennessee, and a portion of Alabama. To the northeast, in Pennsylvania, this coal-field is much broken into patches, as shown in the accompanying map of a part of the State, the black areas being those of the coal-district.

2. The *Michigan* area, covering the central part of the State of Michigan.

3. The *Illinois* or *Eastern Interior* area, covering much of Illinois, and part of Indiana and Kentucky.

4. The *Missouri*, or *Western Interior*, covering part of Iowa, Minnesota, Missouri, Kansas, Arkansas, and Northern Texas.

Fig. 278.



Map of part of Pennsylvania, showing the Coal areas of the State, in black; also the Mesozoic red sandstone formation, obliquely lined across.

5. Besides these, there is a barren Carboniferous region about the slopes and summits of the Rocky Mountains, as around the Great Salt Lake in Utah, and also in California, — the workable coal-beds of the Rocky Mountain region being Cretaceous or Tertiary.

III. ARCTIC REGION. — On Melville Island, and other islands between Grinnell Land and Banks Land, mostly north of latitude 70°, and on Spitzbergen and Bear Island north of Siberia.

The areas of the coal-measures in North America have been estimated as follows:

1. Rhode Island	500 square miles.
2. Nova Scotia and New Brunswick	18,000 “ “
3. Alleghany	60,000 “ “
4. Michigan	5,000 “ “
5. Illinois and Missouri	120,000 “ “

But of these, the *workable* portion probably does not exceed 120,000 square miles.

Carboniferous strata occur also in Great Britain and various parts of Europe. The beds in England are distributed over an area between South Wales on the west and the Newcastle basin on the northeast coast (as shown by the black areas on the following map), the most important for coal being the South Wales region; the Lancashire district, bordering on Manchester and Liverpool; the Yorkshire, about Leeds and Sheffield; and the Newcastle. In South Wales the thickness of the coal-measures is 7,000 to 12,000 feet, with more than 100 coal-beds, 70 of which are worked.

Scotland has some small areas between the Grampian range on the north and the Lammermuirs on the south; and Ireland, several coal-regions of large extent, as at Ulster, Connaught, Leinster (Kilkenny) and Munster.

The coal-fields of Europe which are most worked are the Belgian, bordering on and passing into France. Germany contains only small coal-bearing areas; and Russia in Europe still less, although the Subcarboniferous and Permian rocks cover large portions of the surface.

The area of the coal-measures in Great Britain and Ireland is about 12,000 square miles; in Spain, 4,000; in France, 2,000; Belgium, 518.

Valuable coal-beds are not found in any rocks older than

those of the Carboniferous age, although black carbonaceous shales are not uncommon even in the Lower Silurian. They occur, however, in different Mesozoic formations, and also

Fig 279.

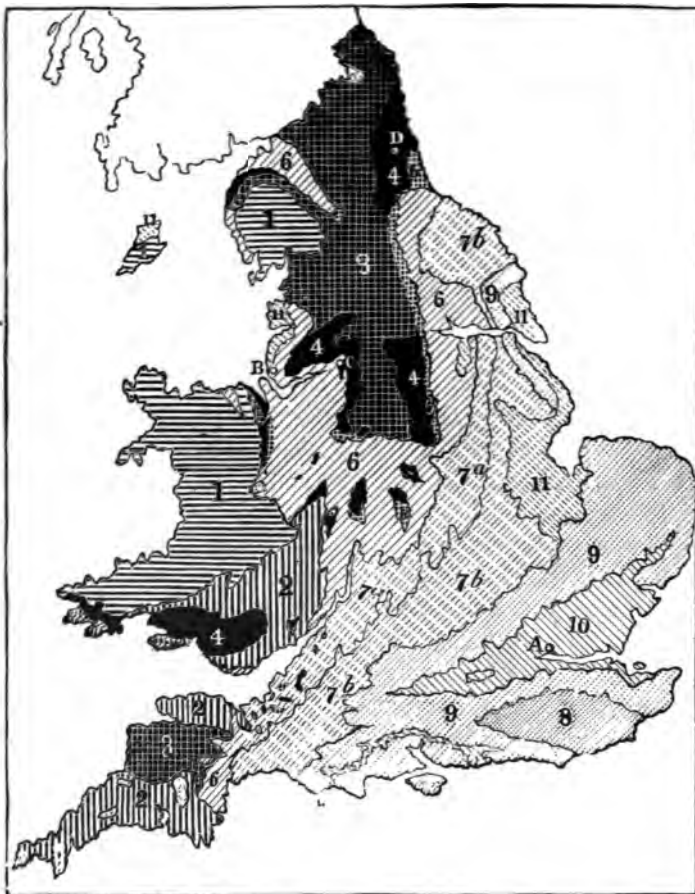


Fig. 279, Geological Map of England. The areas lined horizontally and numbered 1 are Silurian. Those lined vertically (2), Devonian. Those cross-lined (3), Subcarboniferous. Carboniferous (4), black. Permian (5). Those lined obliquely from right to left, Triassic (6). Lias (7 a), Oolite (7 b), Wealden (8), Cretaceous (9). Those lined obliquely from left to right (10, 11), Tertiary. A is London, B, Liverpool, C, Manchester, D, Newcastle.

occasionally in the Cenozoic, but not of the extent which they have in the Carboniferous formations.

3. Kinds of Rocks.

1. **Subcarboniferous Period.** — The Subcarboniferous strata in the *Interior Continental* region are mainly limestone; and, as the limestone abounds in many places in Crinoidal remains, the rock is often called the *Crinoidal limestone*. In the *Appalachian region*, in Middle and Southern Virginia, the rock is also limestone, and has great thickness; but in Northern Virginia and Pennsylvania it is mostly a sandstone or conglomerate overlaid by a shaly or clayey sandstone and marlytes of reddish and other colors, — the whole having a maximum thickness of 5,000 to 6,000 feet. In the *Eastern border region*, in Nova Scotia, the rocks are mostly reddish sandstone and marlyte, with some limestone, — the estimated thickness 6,000 feet.

The prevailing rock in Great Britain and Europe is a limestone, called there the Mountain limestone.

2. **Carboniferous Period.** — 1. *Rocks of the Coal-formation.* — The rocks of the Carboniferous period — that is, those of the Coal-measures — are sandstones, shales, conglomerates, and occasionally limestones; and they are so similar to the rocks of the Devonian and Silurian ages that they cannot be distinguished except by the fossils. They occur in various alternations, with an occasional bed of coal between them. The coal-beds, taken together, make up not more than *one fiftieth* of the whole thickness; that is, there are 50 feet or more of barren rock to 1 foot of coal. The maximum thickness in Pennsylvania is 4,000 feet; in Nova Scotia, 13,000 feet.

The following is an example of the alternations:—

1. Sandstone and conglomerate beds	120 feet.
2. COAL	6 “
3. Fine-grained shaly sandstone	50 “
4. <i>Siliceous iron-ore</i>	1½ “
5. Argillaceous sandstone	75 “

6. COAL, upper 4 feet shale, with fossil plants, and below a thin clayey layer	7 feet
7. Sandstone	80 "
8. Iron-Ore	1 "
9. Argillaceous shale	80 "
10. LIMESTONE (oolitic), containing <i>Producti</i> , <i>Crinoids</i> , etc.	11 "
11. Iron-Ore, with many fossil shells	3 "
12. Coarse sandstone, containing trunks of trees	25 "
13. COAL, lying on 1 foot slaty shale with fossil plants	5 "
14. Coarse sandstone	12 "

The limestone strata are more numerous and extensive in the *Interior Continental* region than in the *Appalachian*; west of the States of Missouri and Kansas limestone is the prevailing rock.

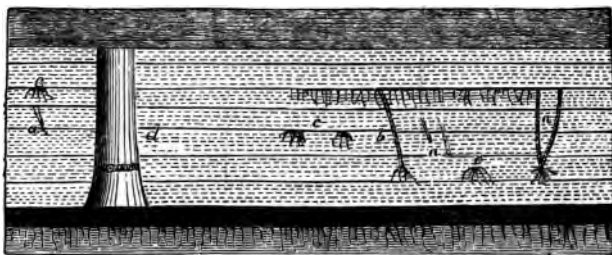
Beds of argillaceous iron-ore or clay-ironstone are very common in coal-districts, so that the same region affords ore and the coal for smelting it. Some of the largest iron-works in the world, on both sides of the Atlantic, occur in coal-districts. The ore is usually the carbonate of iron, impure from mixture with some earth or clay.

The coal-beds often rest on a bed of grayish or bluish clay, called the *under-clay*, which is filled with the roots or under-water stems of plants. When this under-clay is absent, the rock below is usually a sandstone or shale. Above the coal-bed the rock may be sandstone, shale, conglomerate, or even limestone; often the layer next above, especially if shaly, is filled with fossil leaves and stems. In some cases, trunks of old trees rise from the coal and extend up through overlying beds, as in the annexed figure, by Dawson, from the Nova Scotia Coal-measures. Occasionally, as in Ohio and Pennsylvania, logs 50 to 60 feet long lie scattered through the sandstone beds, looking as if a forest had been swept off from the land into the sea.

2. Coal-Beds. — The coal-beds vary in thickness from a fraction of an inch to 30 or 40 feet, but seldom exceed 8 feet, and are generally much thinner: 8 to 10 feet is the thickness of the principal bed at Pittsburg, Pa.; 29½ feet, that of the

"Mammoth Vein" at Wilkesbarre, Pa.; $37\frac{1}{2}$ feet, that of one of the two great beds at Pictou in Nova Scotia. In these thick beds, and often also in the thin ones, there are some intervening beds of shale, or of very impure coal, so that the whole is not fit for burning.

Fig 280.



Section of a portion of the Coal-measures at the Joggins, Nova Scotia, having erect stumps, and also "rootlets" in the under-clays.

The coal varies in kind, as explained on page 18, that burning with little flame being called *anthracite*, and that with a bright yellow flame *bituminous coal*. When only 12 or 15 per cent of volatilizable substances are present, it is often called *semi-bituminous* coal. In Pennsylvania the coal of the Pottsville, Lehigh, and Wilkesbarre regions is *anthracite*; that of Pittsburg and the West, *bituminous* coal; and that of part of the intermediate district, *semi-bituminous*, as designated on the map, page 242.

The coal also varies as to the impurities present. All of it contains more or less of earthy material, and this earthy material constitutes the ashes and slag of a coal-fire. Ordinary good anthracite contains 7 to 12 pounds of impurities in a hundred pounds of coal, and the best bituminous coals 3 to 7. In some coal-beds there is much sulphide of iron or *pyrite* (a compound of sulphur and iron), and the coal is then unfit for use. It is seldom that the sulphide is altogether absent; it is the chief source of the sulphur gases that are perceived in the smoke or gas from a coal-fire.

Mineral coal, although it seldom breaks into plates unless quite impure, still consists of thin layers. Even the hardest anthracite is delicately banded, as seen on a surface of fracture when it is held up to the light. This structure is absent in the variety called *Cannel* coal, which is a bituminous coal, very compact in texture, feeble in lustre, and smooth in fracture.

3. Mineral Oil.—Besides mineral coal, the rocks sometimes afford *mineral oil*, or *petroleum*, and *burning gas*. The oil, when purified for burning, is called *kerosene*. The oil and gas are related compounds of carbon and hydrogen. They are obtained in Pennsylvania by boring through the surface rocks down to the upper Devonian. When the boring reaches the oil-level, the oil rises to the surface, and sometimes issues in a jet. The greatest oil region of this continent is in Western Pennsylvania, over a belt of country about forty miles wide, extending from Greene Co. in the southwestern part of the State, northeastward to McKean Co., and reaching into Allegany Co., N. Y. This belt contains many productive areas, and hundreds of oil-wells. In 1891 the wells near Bradford, in McKean Co., yielded nearly $5\frac{1}{2}$ millions of barrels of oil; those of Allegheny, in which Pittsburg is situated, yielded over $10\frac{1}{3}$ millions; and all Western Pennsylvania nearly 32 millions. All the other oil-regions of the United States yielded in 1891 about 22 millions, and of this $17\frac{3}{4}$ millions were from Ohio. A barrel holds 42 gallons. The rock to which the Pennsylvania wells descend is usually a coarse and very porous sandstone; the oil is in its pores. It is supposed that the oil in the "oil-sands" was derived from subjacent Devonian black or carbonaceous shales, by means of a gentle heating of the rocks during a period of upturning, and that it became condensed in the pores or cavities of the rocks above. Such shales, like coal, do not contain the oil; but they contain some carbo-hydrogen compound which yields oil when heated. But others have thought that the "oil-sands" originally contained the vegetable, or

vegetable and animal, debris from which the contained oil was made by decomposition. The gas comes from the same regions as the oil. But it appears to be mostly obtained from anticlinal belts, where the upward-bent rocks had made a convenient covering for its confinement.

3. Permian period.—The upper part of the Carboniferous formation (mostly barren of coal) in Pennsylvania and Virginia has been shown by its plants, and of Illinois, Kansas, and Texas, by its fossil reptiles or mollusks, to be Permian. Permian strata occur also in the Rocky-Mountain region. The rocks are mostly reddish and gray sandstones and shales, with some impure limestone. Similar rocks occur in Great Britain in the vicinity of several of the coal-regions, and also in Germany and Russia.

4. Life.

1. Plants.

The plants of the forests, jungles, and floating islands of the Carboniferous age, thus far made known, number about 900 species. Among the fossils there are none that afford satisfactory evidence of the presence of either *Angiosperms* or *Palms* (page 189); for no net-veined leaves, allied in character to those of the *Oak*, *Maple*, *Willow*, *Rose*, etc., have been found among them; and no *palm-leaves* or *palm-wood*. Moreover, the plains were without grass, and the swamps and woods without moss. At the present day Angiosperms, along with Conifers or the Pine family, make up the great bulk of our shrubs and trees; Palms abound in all tropical countries; grass covers all exposed slopes where the climate is not too arid; and mosses are the principal vegetation of most open marshes.

The view in Fig. 281 gives some idea of the Carboniferous vegetation over the plains and marshes of the era.

The Carboniferous species, like their predecessors in the Devonian age, belonged to the following groups:—

Fig. 281.



Carboniferous Vegetation.

I. Cryptogams, or Flowerless Plants, *Order of* *Acrogens.*

1. Fern Tribe. — Ferns were very abundant, a large part of the fossil plants of a coal-region being their delicate fronds (usually called leaves). A portion of a fossil fern is repre-

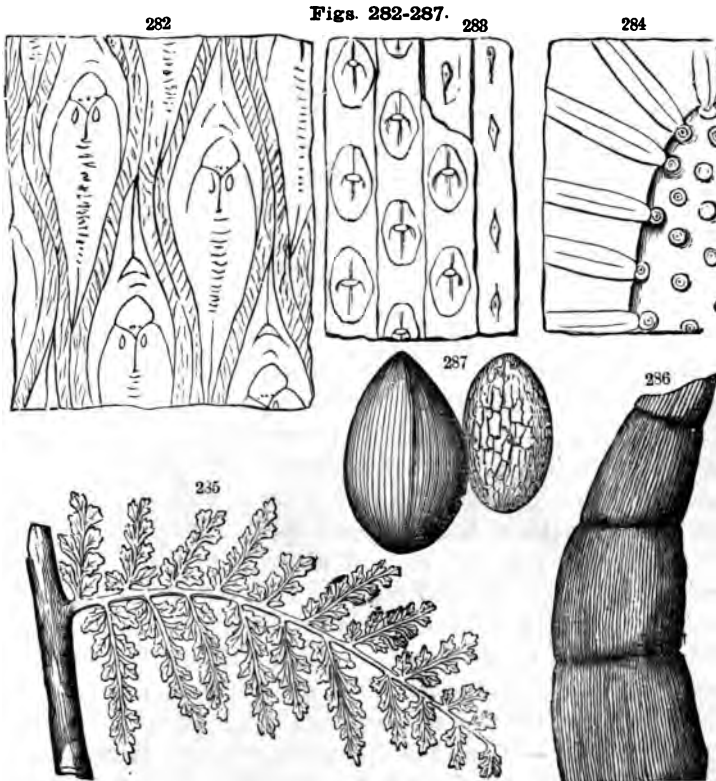


Fig. 282, *Lepidodendron aculeatum*; 283, *Sigillaria oculata*; 284, *Stigmaria ficoides*; 285, *Sphenopteris Gravenhorstii*; 286, *Calamites cannaeformis*; 287, *Trigonocarpus tricuspidatus*.

sented in Fig. 285. Besides small species, like the common kinds of the present day, there were *Trec-ferns*, species that

had a trunk, perhaps 20 or 30 feet high, and which bore at top a radiating tuft of the very large leaf-like fronds, resembling the modern tree-fern of the tropics. One of the tree-ferns of the Pacific is represented in Fig. 281, near the middle of the view, and smaller ferns in front of it below. Tree-ferns, however, were not very common in the Carboniferous forests. The scars in fossil or recent tree-ferns are many times larger than those of *Lepidodendrids*, and the fossils may be thus distinguished.

2. *Lycopodium* Tribe. — 1. The *Lepidodendrids* appear to have been among the most abundant of Carboniferous forest-trees, especially in the earlier half of the Carboniferous Age, or to the middle of the Coal Period. They probably covered both the marshes and the drier plains and hills. Some of the old logs now preserved in the strata are 50 to 60 feet in length, strikingly contrasting with the little Ground-Pines of modern times; and the pine-like leaves were occasionally a foot or more long. The taller tree to the left, on page 250, is a *Lepidodendron*. Fig. 282 shows the surface-markings of one of the species, natural size.

2. *Sigillariæ*. — The *Sigillariæ* were a very marked feature of the great jungles and damp forests of the Coal period. They grew to a height sometimes of 30 to 60 feet; but the trunks were seldom branched, and must have had a stiff, clumsy aspect, although covered above with long, slender, rush-like leaves. Fig. 283 represents a common species, exhibiting the usual arrangement of the scars in vertical lines, and also indicating, by the difference in the scars of the right row from those of the others, their difference of form on the outer surface of the tree and beneath the surface.

3. *Stigmaria*. — The fossil *Stigmaria* are stout stems, generally 2 to 3 or more inches thick, having over the surface distinct rounded punctures or depressions. Fig. 284 is a portion of the extremity of a stem, showing the rounded depressions and also the leaf-like appendages occasionally observed. The stems or branches are a little irregular in form, and spar-

ingly branched. They have been found spreading, like roots, from the base of the trunk of a *Sigillaria*, and sometimes also from that of a *Lepidodendron*; and they are hence regarded either as the roots or subaqueous stems of these trees. They are an exceedingly common fossil, especially in the underclays of the Coal-measures (page 246).

3. Equisetum Tribe. — Fig. 286 represents a portion of one of the tree-rushes, or *Calamites*, of the Equisetum or Horsetail tribe. The specimens were very abundant in the great marshes, through the whole of the Carboniferous Age. Some of them were 20 feet or more high and 10 or 12 inches in diameter.

Besides these Cryptogams there were also *Fungi*; but, as already stated, no remains of Mosses from the rocks of the age are known.

In the ideal view of a Carboniferous landscape, Fig. 281, page 250, the broken trunk to the right is a *Sigillaria*. The landscape, to be quite true to nature, should have been made up largely of *Sigillariæ*, *Calamites*, and *Lepidodendra*, with few tree-ferns. The *Stigmaria* should have been mostly concealed beneath the water or soil, or in the submerged mass of the floating islands.

II. Phenogams, or Flowering Plants, Order of Gymnosperms.

1. Conifers. — Trunks of trees, Coniferous in character, and related especially to the *Araucanian* pines, are not uncommon.

2. Fruits. — Besides the leaves, stems, and trunks already alluded to, there are various nut-like fruits found in the Carboniferous strata. One is represented in Fig. 287 (page 251), the figure to the left being that of the shell, and the other that of the nut which it contained. Some of them are two inches in length. The most of them were probably the fruit of *Conifers*.

It is seen from the above that —

1. The vegetation of the Carboniferous age consisted very largely of Cryptogams, or flowerless plants.

2. The flowering plants, or Phenogams, associated with the flowerless vegetation, were of the order of Gymnosperms, whose flowers are imperfect and inconspicuous.

3. While, therefore, there was abundant and beautiful foliage (for no foliage exceeds in beauty that of Ferns), the vegetation was nearly flowerless.

4. The characteristic Cryptogams were not only of the highest group of that division of plants, but in general they exceeded in size and perfection the species of the present day, many being forest-trees.

2. Animals.

1. **Radiates.** — Among Radiates, species of Crinoids were especially numerous in the Subcarboniferous period. Figs. 288, 289, 290 represent some of the species. The radiating arms are perfect in Fig. 288, but wanting in 289. Fig. 290 is a species of the genus *Pentremites* (named from the Greek *πέντε*, *five*, alluding to the five-sided form of the fossil). The *Pentremites* had a stem made of calcareous disks, like other Crinoids, but no long radiating arms at top.

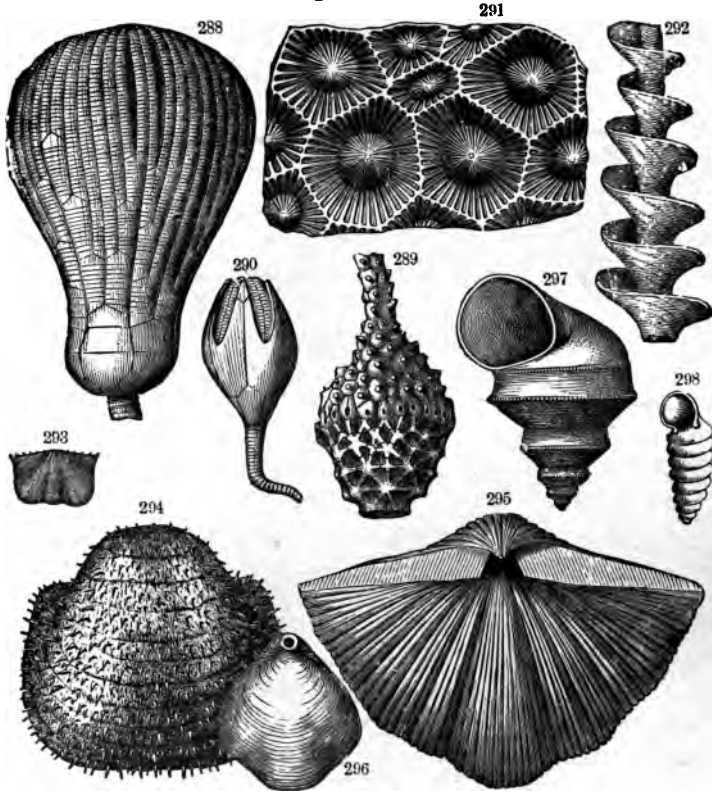
Fig. 291 presents an upper view of a very common Coral of the same period: it has a columnar appearance in a side view.

2. **Mollusks.** — The tribe of Bryozoans contained the singular screw-shaped (or auger-shaped) Coral shown in Fig. 292, and named *Archimedes* (referring to Archimedes' screw). It is made up of minute cells that open over the lower surface; each of the cells, when alive, contained a minute Bryozoum (page 183). These fossils are common in some of the Subcarboniferous limestone strata.

Brachiopods were the most abundant of Mollusks through the Carboniferous age, and especially species of the genera *Spirifer* and *Productus*. Figs. 293 to 296 are of species from the American Coal-measures: Fig. 295, a *Spirifer*; Fig. 294, a *Productus*; Fig. 293, a *Chonetes*; Fig. 296, an *Athyris*, occurring also in Europe. Fig. 297 represents one of the Gas-

teropods of the Coal-measures. Fig. 298 is a *Pupa*, the earliest yet found of land-snails: it is from the Coal-measures of

Figs. 288-298.

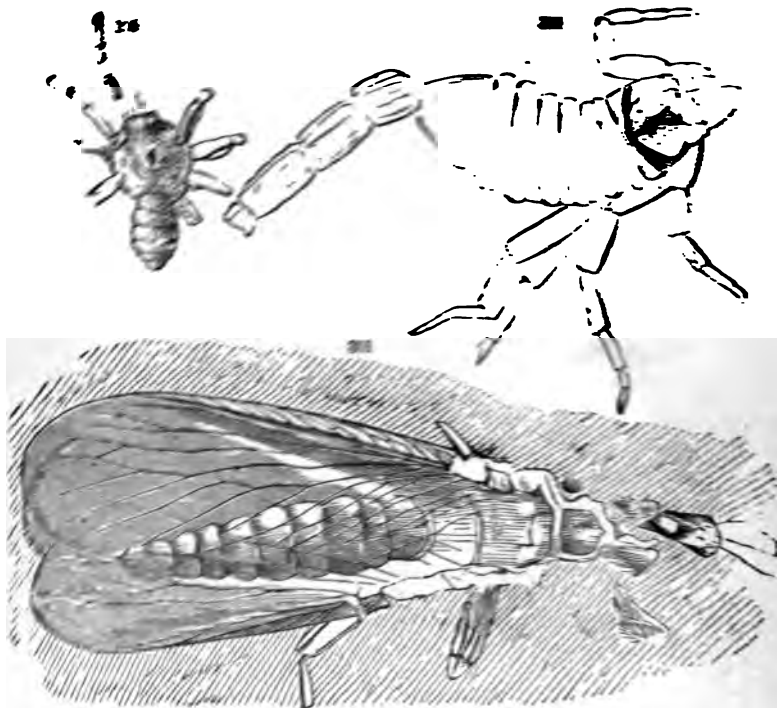


RADIATES: Fig. 288, *Zeacrinus elegans*; 289, *Actinocrinus proboscidealis*; 290, *Pentremites pyriformis*; 291, *Lithostroton Canadense*. — **MOLLUSKS:** Fig. 292, *Archimedes reversa*; 293, *Chonetes mesoloba*; 294, *Productus Nebrascensis*; 295, *Spirifer cameratus*; 296, *Athyris subtilita*; 297, *Pleurotomaria tabulata*; 298, *Pupa vetusta*.

Nova Scotia; others have been found in Illinois. The order of Cephalopods contained but few and small species of the old tribe of *Orthocerata*, but many of the Ammonite-like *Goniatites*.

3. **Articulata**. — Among Articulata, Crustaceans appeared under a new form, much like that of modern shrimps, and *Trilobites* were of rare occurrence.

FIG. 299-301



SPIDERS: Fig. 299, *Arthrolycosa antiquus*; 300, *Eoscorpion carbonarius*. — INSECT: Fig. 301, *Miamia Bronsoni*.

Besides Insects (Fig. 301), there were also Myriapods, true Spiders (Fig. 299), and Scorpions (Fig. 300); the figures are of Illinois species. The Insects include *May-flies* (Neuroptera), *Locusts* and *Cockroaches* (or Orthopterous insects), and *Beetles* (or Coleoptera).

4. **Vertebrates**. — *Fishes* were numerous, both of the orders of Ganoids and Selachians. All the Ganoids were of the an-

cient type, having the tail vertebrated (or heterocercal), as in Fig. 302, representing a Permian species of *Palæoniscus*. Many of the Selachians, or Sharks, were of great size, as shown by the fin-spines. Fig. 303 represents a small portion of one of these spines, natural size, from the Subcarboniferous beds of Europe. One of the largest specimens of the same species when entire must have been 18 inches long.

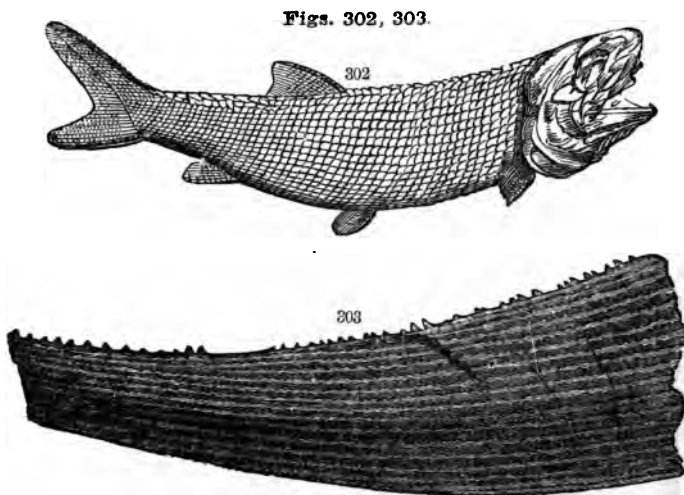


Fig. 302, *Palæoniscus Freieslebeni* ($\times \frac{1}{2}$); 303, Part of a spine of *Ctenacanthus major*.

Amphibian Reptiles occur through the age. They are called *Labyrinthodonts*, because the teeth, like those of the Ganoids, are labyrinthine in the arrangement of the dentine. The earliest traces are tracks found in the Subcarboniferous beds at Pottsville, Pa. (Fig. 304); they are about four inches broad, those of the fore-feet, as described by Dr. Lea, 5-fingered, and those of the hind-feet 4-fingered. Fig. 305 represents a skeleton of another species from the Ohio Coal-measures, found by Newberry. Some of the related Amphibians from Ohio are long, like snakes.

True Reptiles appear to have been represented in the Coal period by swimming species, or *Enaliosaurs*; and, in the Per-

Figs. 304-306.

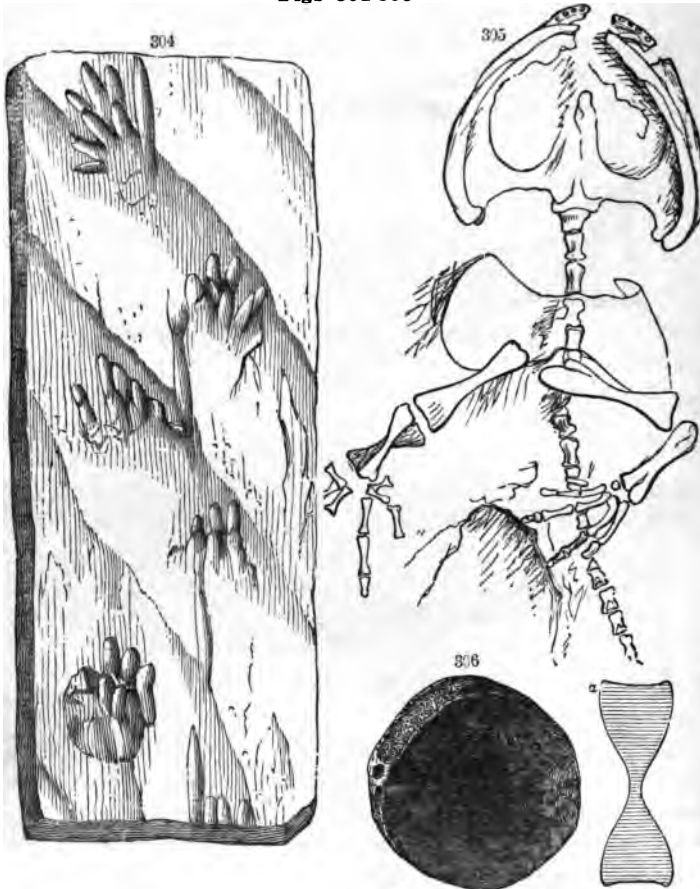


Fig. 304, Tracks of *Sauropus primævus* ($\times \frac{1}{2}$); 305, *Raniceps Lyellii*; 306, a, Vertebra of *Eosaurus Acadianus*.

mian period, by higher Crocodile-like Reptiles of the tribe of *Thecodonts*. The *Enaliosaurs* (or *sea-lizards*, as the word signifies) had paddles like whales, and doubly concave vertebrae,

like fishes. (Figs. 361 and 365 represent Mesozoic species.) A vertebra, found by Marsh in Nova Scotia, and referred by him to the Enaliosaurs, is represented in Fig. 306; and Fig. 306 *a*, a transverse section, shows the biconcave character. The Thecodonts also had the fish-like character of biconcave vertebræ. They had the teeth in sockets, like the Crocodiles, and hence the name *Thecodont*.

5. General Observations.

1. **Formation of Coal, and origin of the Coal-measures.** — 7. *Origin of the Coal.* — The vegetable origin of coal is proved by the following facts: —

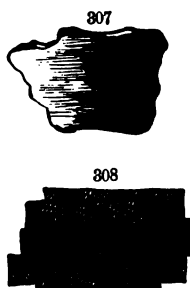
1. Trunks of trees, retaining still the original form and part of the structure of the wood, have been found changed to mineral coal, both in the Carboniferous strata and in more modern formations, showing that the change may and does take place.

2. Beds of peat, a result of vegetable growth and accumulation, exist in modern marshes; and in some cases they are altered below to an imperfect coal. (See page 75, on the formation of peat.)

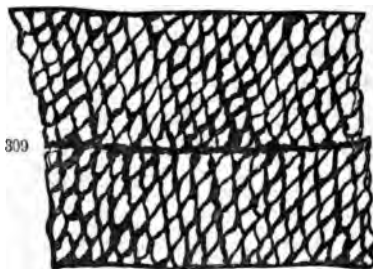
3. Remains of plants, their leaves, branches, and stems or trunks, abound in the Coal-measures; trunks sometimes extend upward from a coal-bed into and through some of the overlying beds of rock; roots or stems abound in the under-clays.

4. The hardest anthracite contains throughout its mass vegetable tissues. Professor Bailey examined with a high magnifying power several pieces of anthracite burnt at one end, like Fig. 307, taking fragments from the junction of the white and black portion, and detected readily the tissues. Fig. 308 represents the ducts, as they appeared in one case under his microscope; and Fig. 309 part of the same, more magnified. Fig. 310 shows the appearance of the *spores* of Lycopods (*Lepidodendrids*) much magnified; they are common in coal.

2. *Decomposition of Vegetable Material.* — The Mineral Coal of the Coal-measures consists (impurities excluded) of 77 to 97 per cent of carbon along with 2 to 6 of hydrogen and 2 to 15 of oxygen; and woody material, whether of Conifers, Ferns, Lycopods, or Equiseta, consists of about 50 per cent of carbon, 6 of hydrogen, and 44 of oxygen. To change the vege-



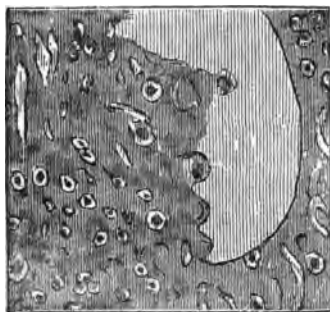
Figs. 307-309.



Vegetable tissues in Anthracite.

table material to coal, it is necessary to get rid of part of the *oxygen* and *hydrogen*. Vegetable matter decomposing in the

Fig. 310.

Spores and part of a Sporangium in bituminous coal of Ohio ($\times 70$).

open air — like wood burnt in an open fire — passes into gaseous combinations, and little or no carbon is left behind. Both the oxygen of the air and that of the wood take part in the combustion or decomposition. But if the *former* is more or less excluded by a covering of earth (as of strata) or of water (as in a swamp), the combustion is incomplete, and *coal* may result, consisting of the uncon-

sumed carbon combined with some hydrogen and oxygen.

The actual loss, by weight, in the transformation into bitu-

minous coal, is at least *three fifths* of the *wood*, and in that into anthracite, *three fourths*. Adding to this loss that from compression, by which the material is brought to the density of mineral coal, the whole reduction in bulk is not less than to *one fifth* for the former, and to *one eighth* for the latter. In other words, it would take 5 feet of vegetable matters to make 1 of bituminous coal, and 8 feet to make 1 of anthracite.

3. Impurities in Coal. — The coal thus formed derived some silica and other earthy ingredients from the wood itself, and alumina from the *Lepidodendrids*, this earth existing in the ash of modern *Lycopods*. By this means the best coal received some earthy impurities, while the poorer coals contain clay or earthy material carried over the marshes by the waters or winds. Sulphur is a common impurity; it usually occurs combined with iron, forming pyrite or sulphid of iron.

4. Accumulation and Formation of Coal-beds. — The origin of coal-beds was, then, as follows: The plants of the great marshes and shallow lakes of the Coal era, the latter with their *floating islands* of vegetation, continued growing for a long period, dropping annually their leaves, and from time to time decaying stems or branches, until a thick accumulation of vegetable remains was formed, — probably 5 feet in thickness for a one-foot bed of bituminous coal. The bed of material thus prepared over the vast wet areas of the continent early commenced to undergo at bottom that slow decomposition the final result of which is mineral coal. But, as the coal-beds alternate with sandstones, shales, conglomerates, and limestones, the long period of verdure was followed by another of overflowing waters, — and generally, in the case of the region of the Interior basin of North America, oceanic waters, as the fossils prove, — which carried sands, pebbles, or earth, over the old marsh, till scores or hundreds of feet in depth of such deposits had been made. Thus the bed of vegetable material was buried; and under this condition the process of decomposition and change to mineral coal went forward to its completion; it had the smothering influence of

the burial, as well as the presence of water, to favor the process.

5. *Climate of the Age.* — The wide distribution of the coal regions over the globe, from the tropics to remote Arctic lands, and the general similarity of the vegetable remains in the coal-beds of these distant zones, prove that there was a general uniformity of climate over the globe in the Carboniferous age, or at least that the climate was nowhere colder than *warm-temperate*. Besides, corals and shells existed during the Subcarboniferous period in Europe, the United States, and the Arctic within 20° of the north pole, and so profusely as to form thick limestones out of their accumulations; and some Arctic species are identical with those of Europe and America. The ocean's waters, even in the far north, were, therefore, warm compared with those of the modern temperate zone, and probably quite as warm as the coral-reef seas of the present age, which lie mostly between the parallels of 28° either side of the equator.

6. *Atmosphere.* — The atmosphere was especially adapted for the age in other respects. It contained a larger amount than now of carbonic-acid gas, — the gas which promotes (if not in excess) the growth of vegetation. Plants derive their carbon mainly from the carbonic acid of the atmosphere; and hence the mineral coal of the world is approximately a measure of the amount of carbonic acid the atmosphere in the Carboniferous era lost. The growth of the flora of that age was a means of purifying the atmosphere so as to fit it for the higher terrestrial life that was afterward to possess the world.

Again, the atmosphere was more *moist* than now. This follows from the greater heat of the climate and the greater extent as well as higher temperature of the oceans. The continents, although large during the intervals of verdure compared with the areas above the ocean in the Devonian or Silurian, were still small and the land low. It must, therefore, have been an era of prevailing clouds and mists. A moist climate would not, however, have been universal, since even

the ocean has now its great areas of drought depending on the courses of the winds. America is now the moist forest-continent of the globe; and the great extent of the coal-fields of its northern half proves that it bore the same character in the Carboniferous age.

2. Geography. — *1. Appalachian and Rocky Mountains not made.* — On page 240 it is stated that the continents in this age were low, with few mountains. The non-existence of the Appalachians of Pennsylvania and Virginia is proved by the fact that the rocks of these mountains are to a considerable extent Carboniferous rocks; — partly *marine* rocks, indicating that the sea then spread over the region; partly *coal-beds*, each bed evidence that a great fresh-water marsh, flat as all marshes are, for a long while occupied the region of the present mountains.

There is the same evidence that the mass of the Rocky Mountains had not been lifted; for marine Carboniferous rocks constitute a large part of these mountains, many beds containing remains of the life of the Carboniferous seas that covered that part of North America. Only islands, or archipelagoes of islands, made by some Archæan and perhaps also Paleozoic ridges, existed in the midst of the widespread western waters.

2. Condition in the Subcarboniferous Period. — Through the first period of this age — the Subcarboniferous — the continent was almost as extensively beneath the sea as in the Devonian age. This, again, is shown by the nature and extent of the Subcarboniferous rocks, — the great crinoidal limestones. The shallow continental seas were profusely planted with Crinoids amid clumps of Corals. Brachiopods were here and there in great abundance, many lying together in beds as oysters in an oyster-bed; other Mollusks, both Lamellibranchs and Gasteropods, were also numerous; Trilobites were few; Goniatites and Nautili, along with Ganoid Fishes and Sharks, were the voracious life of the seas, and Amphibian reptiles haunted the marshes.

3. Transition to the Carboniferous Period. — Finally, the Sub-carboniferous period closed, and the Carboniferous opened. But in the transition from the period of submergence to that of emergence, required to bring into existence the great marshes, a widespread bed of pebbles, gravel, and sand was accumulated by the waves dashing rudely over the surface of the rising continent; and these pebble-beds make the *Millstone grit* that marks the commencement of the Carboniferous period in a large part of Eastern North America, especially along the Appalachian region, and also in Europe.

4. Coal-plant Areas in the Carboniferous Period. — Then began the epoch of the *Coal-measures*.

The positions of the great coal areas of North America (see map, page 195) are the positions, beyond question, of the great marshes and shallow fresh-water lakes of the period. But it is probable that the number of these marshes was less than that of the coal areas. The Appalachian, Illinois, Missouri, Arkansas, and Texas fields may have made one vast *Interior continental* marsh-region, and those of Rhode Island, Nova Scotia, and New Brunswick an *Eastern border* marsh-region connected over Massachusetts Bay and the Bay of Fundy. There is reason, however, for believing that a low area of dry land extending from the region of Cincinnati into Kentucky (page 217) divided at least the northern portion of the Interior marsh.

The Michigan marsh-region appears also to have had its dry margins, instead of coalescing with the Illinois or Ohio areas.

It is not to be inferred that the marshes alone were covered with verdure. The vegetation probably spread over all the dry land, though making thick deposits of vegetable remains only where there were marshes under dense jungles and shallow lakes with their floating islands.

5. Alternations of Condition: Changes of Level. — It has been remarked that the many alternations of the coal-beds with sandstones, shales, conglomerates, and limestones (page 245),

are evidence of as many alternations of level, or at least of conditions, during the era. After the great marshes of the Continental Interior had been long under verdure, the salt waters began again to encroach upon them in consequence of a sinking of the land, and finally swept over the whole surface, destroying the terrestrial and fresh-water life of the area, — that is, the terrestrial and fresh-water Plants, Mollusks, Insects, and Reptiles, — but distributing at the same time the new life of the salt waters. Then, after another long period, one perhaps of many oscillations in the water-level, in which sedimentary beds in many alternations were formed, the continent again rose to aerial life, and the marshes and shallow lakes were luxuriant anew with the Carboniferous vegetation. Thus the sea prevailed at intervals — intervals of long duration — through the era even of the Coal-measures; for the associated sedimentary beds, as has been stated, are at least fifty times as thick as the coal-beds. In the Nova Scotia Coal area, the waters which came in over the coal-beds were the brackish or fresh waters of a great estuary, — that at the mouth of the St. Lawrence River of the Carboniferous period.

These oscillations continued until 3,000 to 4,000 feet of strata were formed in Pennsylvania, and over 14,000 in Nova Scotia.

The Carboniferous period was, therefore, ever varying in its geography. A map of its condition when the great coal-beds were accumulating would have its eastern coast-line not far inside of the present, and in the region of Nova Scotia and New England even *outside* of the present; for there must have been a sea-barrier in order that the deposits in the former region should have been of brackish or fresh-water origin. The southern coast-line would pass through central Carolina, Georgia, Alabama, and Northern Mississippi, then west of the Mississippi, around Arkansas and the bordering counties of Texas; thence it would stretch northward, bounding a sea covering a large part of the Rocky-Mountain region, for the Coal period was, in that part of the continent, mainly a

time of limestone-making. On the contrary, in a map representing it during the succeeding times of submergence, the coast-line would run through Southeastern New England, then near the southern boundary of New York State, then northwestward around Michigan, then southward again to Northern Illinois, and then westward and northwestward to the Upper Missouri region, or the Rocky Mountain sea. Through these conditions, as the extremes, the continent passed several times in the course of the Carboniferous period.

6. Condition in the Permian Period. — Finally, in the Permian period, the Appalachian region, and the Interior region east of a north-and-south line running through Missouri, appear to have been mainly above the ocean; for the Permian beds are mostly confined to the meridians of Kansas and the remoter West.

GENERAL OBSERVATIONS ON THE PALEOZOIC.

1. Rocks. — *1. Maximum thickness.* — The maximum thickness of the rocks of the Silurian age in North America is at least 25,000 feet; of the Devonian, about 14,400 feet; and of the Carboniferous age, about 16,000 feet.

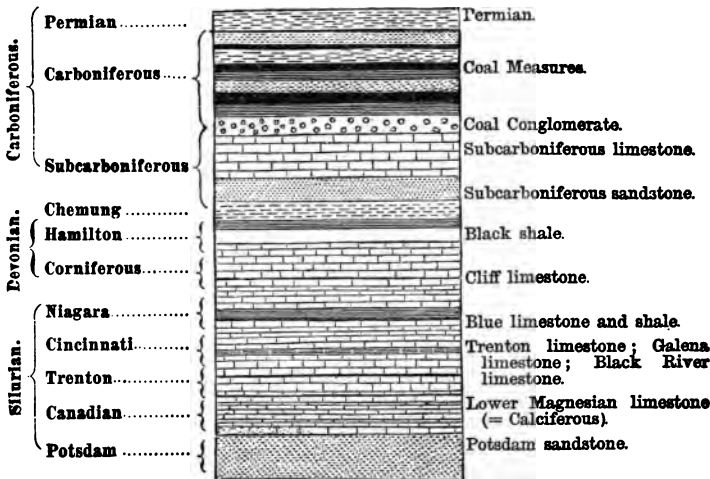
2. Diversities of the different Continental regions as to kinds of rocks. — The Paleozoic rocks of the Appalachian region are mainly sandstones, shales, and conglomerates; only about *one fourth* in thickness of the whole consists of limestone. The rocks of the Interior Continental are mostly limestone, full two thirds being of this nature.

The difference of these two regions, in this particular, will be appreciated on comparing the following general section of the strata of the Interior with the section, on page 193, of the rocks of New York, — New York State lying on the inner border of the Appalachian region. The Lower Silurian beds in the Mississippi basin, as the section shows, consist mainly of limestones; so also the Upper Silurian, Devonian, and Sub-carboniferous formations; and the Carboniferous of the region

contains more limestone than that of the East. In the Devonian of the Interior the Hamilton is represented by a limestone in parts of Michigan, Ohio, Canada West, and Illinois, to Iowa, and besides this there is only a *black shale*, one to three or four hundred feet thick.

In the Eastern-border region, about the Gulf of St. Lawrence, there is a great predominance of limestones in the

Fig. 311.



Section of the Paleozoic rocks in the Mississippi basin.

formations. They prove the existence in that region of an Atlantic-border basin similar in some respects to the basin of the Interior, — the two being separated by the Green Mountains, that is, the northern part of the Appalachian region.

3. *Diversities of the Appalachian and Interior-Continental regions as to the thickness of the rocks.* — In the *Appalachian* region the maximum thickness of the Paleozoic rocks is about 40,000 feet. But this thickness is not observed at any one locality, it being obtained by adding together the greatest thicknesses of the several formations wherever observed. The greatest actual thickness in Pennsylvania is about 30,000 feet, or nearly six miles.

In the central portions of the *Interior-Continental* region the thickness varies from 3,500 feet (and still less on the northern border) to 6,000 feet; and it is, therefore, from *one sixth* to *one tenth* that in the Appalachian region.

4. *Origin of the deposits.* — The material of the *fragmental* rocks, or those of sand, clay, mud, pebbles (the sandstones, shales, earthy sandstones and conglomerates), was made (1) by the wear of pre-existing rocks under the action of water; (2) by disintegration produced by partial decomposition; and (3) by disaggregation from expansion and contraction due to daily and annual changes of temperature. The water was mainly that of the ocean, and the power was that of its waves and currents. But the water from the rains aided in the wear, although there were no large rivers; and, through the carbonic acid it took up from the atmosphere, it was a great agent in the disintegration of exposed rocks, — feldspar, the most common ingredient in crystalline rocks and also nearly all iron-bearing minerals, yielding more or less easily under the action.

The material of the coarser rocks may have accumulated where the waves were dashing against a beach or an exposed sand-reef, or else where currents were in rapid movement over the bottom; for accumulations of pebbles and coarse sand are now made under these circumstances. The material of the earthy sandstones may have been the mud or earthy sands forming the bottom of shallow seas. The fine clayey or earthy deposits must have been made in either sheltered bays or interior seas, in which the waves were light, and therefore fitted to produce by their gentle attrition the finest of mud; or else in the deeper off-shore waters, where the finer detritus of the shores is liable to be borne by the currents.

Accumulations of any degree of thickness may be made in *shallow* waters, provided the region is undergoing very slow subsidence; for in this way the depth of the waters may be kept sufficient to allow of constantly increasing depositions. Thus, by a slow subsidence of 1,000 feet, deposits 1,000 feet

thick may be produced, and the depth of water at no time exceed 20 feet. The occurrence of ripple-marks, mud-cracks, or rain-drop impressions in many beds of most of the formations proves that the layers so marked were successively near the surface, and therefore that there must have been a gradual sinking of the bottom as the beds were formed.

The *limestones* of the Paleozoic were probably made, in every case, out of organic remains, either Shells, Corals, Crinoids, etc., or the minute Rhizopods, which are known to have formed, to a large extent, the chalk-beds of Europe. Shells, Corals, and Crinoids must be ground up by the waves to form fine-grained rocks; while the shells of Rhizopods are so minute as to be already fine grains, and may become compact rocks by simple consolidation.

The *hornstone* in the limestones, as remarked on page 234, may be wholly of organic origin.

2. Time-Ratios. — Judging from the maximum thickness of the rocks of the several Paleozoic ages in North America, and allowing that *five* feet of fragmental rocks may accumulate in the time required for one foot of limestone, the relative lengths of the Silurian, Devonian, and Carboniferous ages were not far from 4 : 1 : 1, and the Lower Silurian era was four times as long as the Upper.

Time moved on slowly in the earth's first beginnings. The condition of the earth in an age of Invertebrates, when all life was the life of the waters, and nothing existed above the ocean's level except it may be the humble lichen or fungus, was very inferior to that of the Carboniferous, when the continents had their forests, the waters their fishes, and the marshes their reptiles. Yet the length of time through which the earth was groping under the first-mentioned condition was vastly longer than under the last. Such is time in the view of the infinite Creator.

3. Geography. — *1. Close of Archæan time.* — The map on page 199 shows approximately the outline of the dry land of North America at the close of the Archæan. The only mountains

were Archæan mountains, the principal of which were the Laurentian of Canada, the Adirondacks of Northern New York, the Highlands of New Jersey and Dutchess County of New York, the Blue Ridge farther to the southwest, and the Wind-River and other eastern ridges of the Rocky Mountain region. We cannot judge of the height of these mountains then from what we now see, after all the ages of Geology have passed over them, for the elements and running water have never ceased action since the time of their uplift, and the amount of loss by degradation must have been very great.

2. *General Progress through Paleozoic time.* — The increase of *dry land* during the Paleozoic has been shown (pages 225, 239) to have taken place mainly along the borders of the Archæan, so that the original area was thus gradually extending. This increase is well marked from north to south across New York. At the close of the Lower Silurian the shore-line was not far from the present position of the Mohawk, indicating but a slight extension of the dry land in the course of this very long era; when the Upper Silurian ended, the shore-line probably extended along a score of miles or so south of the Mohawk. When the Devonian ended and the Carboniferous age was about opening, the coast-line was just north of the Pennsylvania boundary.

The progress southward was at an equal rate in Wisconsin, where there is an isolated Archæan region like that of Northern New York. In the intermediate district of Michigan the coast made a deep northern bend through the Silurian and Devonian. In the Carboniferous the same great Michigan bay existed during the intervals of submergence; but it was changed to a Michigan marsh or fresh-water lake, filled with Coal-measure vegetation, during the intervening portions of the Carboniferous period; and, at the same times, as explained on page 265, the continent east of the western meridian of Missouri had nearly its present extent, though not its mountains or its rivers.

3. *Regions of rock-making, and their differences.* — The sub-

merged part of the continent included far the larger portion, and was the scene of nearly all the rock-making. Areas of fresh-water, however, existed at times, especially in the Devonian and Carboniferous, as is proved by the coal beds, and by occasional fresh-water shells in shales and sandstones.

The rocks, as partially explained on page 269, varied in kind with the depth, and with the exposure to the open sea.

This *Interior Continental* region, which was for the most of the time a great interior oceanic sea, afforded the conditions fitted for the growth of Corals and Crinoids and other clear-water species, and hence for the making of limestone reefs out of their remains; for limestones are the principal rocks of the interior. Yet there were oscillations in the level; for there are abrupt transitions in the limestones, and some sandstones and shales alternate with them. But these oscillations were not great, the whole thickness of the rocks, as stated on page 268, being small.

The *Appalachian* region, on the contrary, presented the conditions required for fragmental deposits. It was apparently a region of immense sand-reefs and mud-flats, with bays, estuaries, and extensive submerged off-shore plateaus. Here the change of level was very great; for within this region occur nearly six miles of Paleozoic formations (page 267). This vast thickness indicates that while there were various upward and downward movements over this Appalachian region through Paleozoic time, the downward movements exceeded the upward even by the amount just stated. These movements were in progress from the Potsdam period onward; the formations of nearly every period exceed 8 to 10 times the thickness they have over the Interior region.

4. *Mountains of Paleozoic origin.* — The mountains in Eastern North America, made in the course of the Paleozoic ages, were few. Those of the region south of Lake Superior about Keweenaw Point, and to the west, probably rose during the Canadian period, the second of the Lower Silurian. The Green Mountain region became dry land after the close of the

Lower Silurian (page 216); but there is no reason to believe that it was at its present level, for the Hudson River Valley east of Hudson, and part or all of the Connecticut Valley, was beneath the ocean, and became covered by crinoidal and coral reefs and other formations during the Lower Helderberg era, and perhaps also during the early Devonian. The Devonian and other beds of the vicinity of Gaspé, and of Nova Scotia and New Brunswick, were raised into ridges before the Carboniferous age began, mountain-making having gone forward in this Atlantic-border region after the close of the Devonian. But the larger part of the continental area remained without mountains. The Rocky chain had only some ridges as islands in the seas, and the Appalachians south of New England were yet to be made.

5. Rivers; Lakes. — The depression between the New York and the Canada Archæan, dating from Archæan time, was the first indication of a future St. Lawrence channel. It continued to be an arm of the sea, or deep bay, through the Silurian, and underwent a great amount of subsidence as it received its thick formations. After the Silurian age marine strata ceased to form, indicating thereby that the sea had retired; and fresh waters, derived from the Archæan heights of Canada and New York, probably began their flow along its upper portion, and emptied into the St. Lawrence Gulf of the time not far below Montreal.

The raising of New York State out of water at the close of the Devonian suggests that from that time the Hudson Valley was a stream of fresh water. The valley itself, and its continuation north as the Champlain Valley, date from the close of the Lower Silurian, if not from the Archæan.

The Mississippi and its tributaries, east and west, were not in existence in the Paleozoic ages. In the intervals of Carboniferous verdure, when the continent was emerged, the Ohio and Mississippi basin were regions of great marshes, lakes, and bayous, and not of great rivers; for rivers could

not exist without a head of high land to supply water and give it a flow.

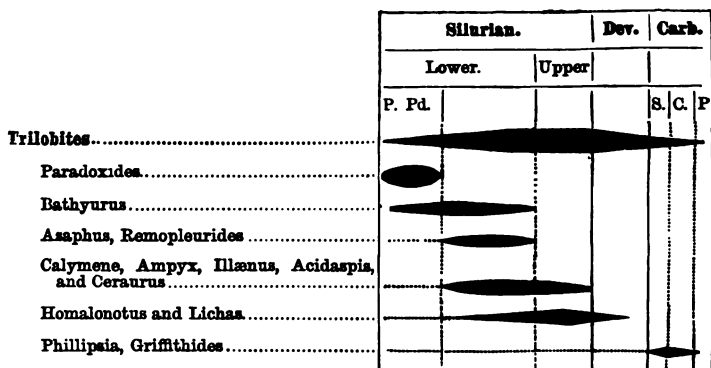
Over portions of Lake Superior there were extensive rock-deposits and igneous eruptions in part of the Canadian period; and the thick accumulations show that deep subsidences were then in progress there, as also in the region of the St. Lawrence; so that we may infer that the basin of this great lake was already in process of formation before the Lower Silurian closed. The extent and position of the great Michigan bay through the Silurian and Devonian ages and much of the Carboniferous, as mentioned on pages 225, 264, show that Lakes Erie, Huron, and Michigan were then within the limits of this bay. Whether deeper or not than other portions of the bay, is not known.

Thus, Geology studies the Geography of the Paleozoic ages, and traces North America through its successive stages of growth.

4. **Climate.** — No evidence has been found through the Paleozoic records of any marked difference of temperature between the zones. In the Carboniferous age the Arctic seas had their Corals and Brachiopods, and the Arctic lands their forests and marshes under dense foliage, no less than those of America and Europe. The facts on this subject are stated on page 262.

5. **Life.** — 1. *Appearance and disappearance of species.* — With the beginning and progress of each formation in the series, new species appeared, and the old ones more or less completely disappeared. Such changes in the life occurred in connection even with the minor transitions in the rock-formations, as in that from a bed of shale to sandstone or to limestone, and the reverse. Thus, through the ages, life and death were in concurrent progress.

2. *Beginning and ending of genera, families, and higher groups.* — The following table of the tribe of Trilobites illustrates the progress which took place in this group and exemplifies the general fact with regard to other tribes: —



The vertical columns correspond to the Lower and Upper Silurian, the Devonian, and the Carboniferous. The left-hand column under Lower Silurian corresponds to the first, or Primordial period; and the three columns under the Carboniferous, to the Subcarboniferous, Carboniferous, and Permian periods of the age. Opposite TRILOBITES, the black area shows that the tribe began with the beginning of the Paleozoic and continued nearly to its end. Next there is the name of a genus which existed only in the Primordial period, it having then many species, but none afterward; with it there were other genera which had species also in the later part of the Lower Silurian. Then there is a genus, Bathyrus, which continued from the Primordial through the Lower Silurian. Then, others confined to the rest of the Lower Silurian; others that passed into the Upper Silurian, then to become extinct; others that continued into the Devonian; and two genera confined to the Carboniferous.

In a similar manner the genera and families of Brachiopods began at different periods or epochs, and continued on for a while, to become, in general, extinct. Many genera ended in the course of the Paleozoic and at its close; only a few continued into later periods.

3. *Special Paleozoic peculiarities of the Life.* — The following facts show in what respects the life of the Paleozoic ages was peculiarly *ancient* : —

a. Not only are the species all extinct, but almost every genus. Fifteen or sixteen of the genera which existed in the course of the Paleozoic have *living* species; and all these are *Molluscan*.

b. Among Radiates, the Polyps were largely of the tribe of *Cyathophylloid* corals, which is almost exclusively ancient or Paleozoic. The Echinoderms were mostly *Crinoids*, and these were in great profusion. Crinoids were far less abundant, and of different genera, in the Mesozoic; and now, few exist.

c. Among Mollusks, *Brachiopods* were exceedingly abundant: their fossil shells far outweigh those of all other Mollusks. But in the Mesozoic they were much less numerous than other Mollusks; and at the present time the group is nearly extinct. The Cephalopods were represented very largely by *Orthoccrata*, but few species of which existed in the early Mesozoic, and none afterward.

d. Among Articulates, *Trilobites* were the most common Crustaceans, — a group *exclusively* Paleozoic.

e. Among Vertebrates, the Devonian Fishes were either *Ganoids*, *Placoderms*, or *Selachians*, and the Ganoids had *vertebrated tails*. Of this kind of Ganoids, but few species lived in the first period of the Mesozoic; and the whole group of Ganoids is now nearly extinct. Of the Selachians, a large proportion were *Cestracionts*, — a tribe common in the Mesozoic, but now nearly extinct.

f. Among terrestrial Plants, there were *Lepidodendrids*, *Sigillarids*, *Calamites* in great profusion, making, with Conifers and Ferns, the forests and jungles of the Carboniferous and later Devonian: no *Lepidodendrid* or *Sigillarid* existed afterward, and the *Calamites* ended in the Mesozoic.

Thus, the Paleozoic or *ancient* aspect of the animal life was produced through the great predominance of *Brachiopods*, *Crinoids*, *Cyathophylloid Corals*, *Orthoccrata*, *Trilobites*, and verte-

brated-tailed *Ganoids*; and that of the plants over the land, through the *Lepidodendrids*, *Sigillarids*, and *Calamites*, along with the Ferns and Conifers. In addition to this should be mentioned the absence of *Angiosperms* and *Palms* among Plants; the absence of *Teliost Fishes*, and of *Birds* and *Mammals*, among Vertebrates; and of *nearly all modern tribes of genera* among Radiates, Mollusks, and Articulates.

4. *Mesozoic and Modern types begun in Paleozoic time.* — The principal *Mesozoic* type which began in the Paleozoic was the Reptilian. But besides these Reptiles there were the first of the Decapod Crustaceans; the first of Oysters; the first of the great tribe of Ammonites, the *Goniatites* being of this tribe; the first of Insects, Spiders and Centipedes. The type of Insects, or terrestrial Articulates, belongs eminently to modern time; for it probably has now its fullest display.

Thus, while the Paleozoic ages were progressing, and the types peculiar to them were passing through their time of greatest expansion in numbers and perfection of structure, there were other types introduced which were to have their culmination in a future age.

DISTURBANCES CLOSING PALEOZOIC TIME.

1. *General quiet of the Paleozoic Ages.* — The long ages of the Paleozoic passed with but few and comparatively small disturbances of the strata of Eastern North America. There were some early permanent uplifts in the Lake Superior region, during the Lower Silurian; again, after the Lower Silurian, the Green Mountains were made; and again, after the close of the Devonian, there were disturbances and upturnings in Eastern New Brunswick, part of Nova Scotia, and Eastern Canada by Gaspé near St. Lawrence Bay. Besides these changes there was, through the ages, a gradual increase on the north in the amount of dry land; and through parts of all the periods, over a large part of the continent, slow oscillations were in progress, varying the water-level and favoring

the increasing thickness of the rocks, and their successive variations as to kind and extent. But these movements of the earth's crust were exceedingly slow, — probably less than a foot a century. There may have been many occasional quakings of the earth, — even exceeding the heaviest of modern earthquakes. There may have been at times sudden risings or sinkings of portions of the continental crust. But the condition of the strata of the interior of the continent, and of the Appalachian region south of the Green Mountains, indicates that general quiet prevailed through the long Paleozoic ages.

2. The Appalachian the region of greatest change of level through the Paleozoic. — The region of greatest movement during these ages was the *Appalachian*. For it has been shown that the oscillations which there took place resulted in subsidences of one or more thousand feet with nearly every period of the Paleozoic. In the Green Mountain portion the oscillations ceased after the close of the Lower Silurian era; but not until the subsidence there had reached probably 15,000 feet; and in Pennsylvania and Virginia they continued through a large part of the Carboniferous age, until the sinking amounted to about 30,000 feet. But this sinking was quiet in its progress, as is proved by the regularity in the series of strata.

The thickness of the coal-beds indicates that the coal-plant marshes were long undisturbed, and therefore that long periods passed without appreciable movement.

3. Approach of the epoch of Appalachian revolution. — The era of comparative quiet alluded to came gradually to a close as the Carboniferous age was terminating, and an epoch of upturning and mountain-making began. There are mountains to testify to this both in Europe and America.

In Eastern North America the disturbances affected Nova Scotia and the coal area of Rhode Island and Southeastern Massachusetts; and, with far grander results, the Appalachian region and Atlantic border from Southern New York to Alabama. The Appalachian mountains are a part of the result,

and hence the epoch is appropriately styled the epoch of the Appalachian revolution. The region in Eastern America of the deepest Paleozoic subsidence and of the thickest accumulation of Paleozoic rocks, that is, the Appalachian, was now the region of the profoundest disturbances and the greatest uplifts.

4. Effects of the disturbances. — The following are among the effects of the disturbances along the Appalachian region and Atlantic border: —

1. Strata were upraised and flexed into great folds, some of the folds a score or more of miles in span.

2. Deep fissures of the earth's crust were opened, and faults innumerable were produced, some of them of 10,000 to 20,000 feet.

3. Rocks were consolidated; and over some parts sandstones and shales were crystallized into gneiss, mica schist, and other related rocks, and limestone into architectural and statuary marble.

4. Bituminous coal was turned into anthracite in Pennsylvania and Rhode Island.

5. In the end, the Appalachian mountains were made.

5. Evidence of the flexures, uplifts, and metamorphism. — The evidence that the rocks of the Appalachian region and Atlantic border were flexed, uplifted, faulted, and otherwise changed from their original condition, is as follows: —

The Coal-measures and other Paleozoic strata, though originally spread out in horizontal beds, are now in an uplifted and flexed or folded condition; and they are so involved to-

Fig. 312.

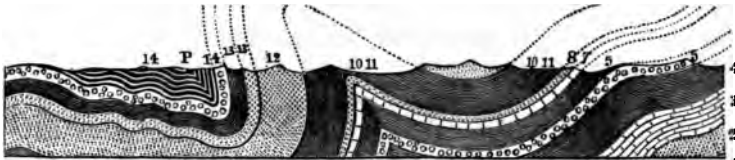


Section at Trevorton Gap, Pa., the dark bands representing coal beds.

gether in one system of flexures and uplifts that the whole must have been the result of one system of movements. Figs. 312-315 illustrate this.

Figs. 312 and 313, and 120 on page 160, represent sections in the coal regions of Pennsylvania. In Fig. 313, the

Fig. 313.



Section on the Schuylkill, Pennsylvania; P., Pottsville on the Coal-measures; 2, Calciferous formation; 3, Trenton; 4, Hudson River; 5, Oneida and Niagara; 7, Lower Helderberg; 8, 10, 11, Devonian; 12, 13, Subcarboniferous; 14, Carboniferous or Coal-measures.

coal-beds are the upper to the left, numbered 14; the rest are beds of underlying Paleozoic formations, as explained under the figure. Fig. 120 shows the complicated folds in the anthracite coal measures, near Mauch Chunk; three steep anticlines occur in 1,200 yards.

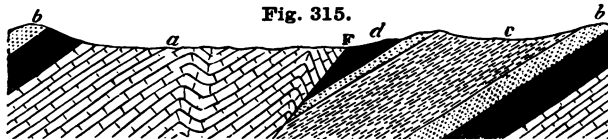
Fig. 314.



Section from the Great North to the Little North Mountain through Bore Springs, Virginia; t, t, position of thermal springs; II, Calciferous formation; III, Trenton; IV, Hudson River; V, Oneida; VI, Clinton and Lower Helderberg; VII, Oriskany Sandstone and Canda-Galli Grit.

Fig. 314 was taken from the vicinity of Bore Springs, in Virginia, and includes Silurian and Devonian beds.

Fig. 315.



Section of the Paleozoic formations of the Appalachians in Southern Virginia, between Walker's Mt. and the Peak Hills (near Peak Creek Valley): F, fault; a, Lower Silurian limestone; b, Upper Silurian; c, Devonian; d, Subcarboniferous, with coal-beds.

Fig. 315 represents one of the great faults in Southern Virginia (between Walker's Mountain and Peak Hills);

the break is at F, and the rocks on the left were shoved up along the sloping fracture until a Lower Silurian limestone (*a*) was on a level with the Subcarboniferous formation (*d*), a fault of more than 10,000 feet. Such examples are in great numbers throughout the Appalachians. In many of the transverse valleys the curves may be traced for scores of miles.

As shown in the above sections (Figs. 312–315), the folds, instead of remaining in regular rounded ridges with even synclinal valleys between, such as the flexing of the strata might make, have been to a great extent worn away, or modelled into new ridges and valleys, by the action of waters during subsequent time; and often what was the top of a fold is now the bottom of a valley, because the folds would be most broken where most abruptly bent, — that is, along the axes of upward flexure, — and hence would be most liable in these parts to be cut away or gorged out by any denuding causes. The figures on page 57 illustrate still further the condition of folded strata before and after denudation. Some of the Appalachian folds were probably 20,000 feet in height above the present level of the ocean, or would have had this height if they had remained unbroken, while in fact the loftiest summits now are less than 5,000 feet, and few exceed 3,000 feet.

Over New England there are similar flexures. Those of the Rhode Island coal-formation are very abrupt, and full of faults, the coal-beds being much broken and displaced.

6. General truths with regard to the results.—The following are some of the general truths connected with the uplifts and metamorphism :—

1. The courses of the flexures and of the outcrops or strike, and those of the great faults, are approximately north-east, or parallel to the Atlantic border. There is a bend eastward in Pennsylvania corresponding with the eastward bend of the southern coast of New England, and then a change to the northward in New England.

2. The folds have their steepest slope *toward the northwest*, or away from the ocean. If Fig. 49 (page 57) represent one of the folds, the left would be the ocean side, or that to the southeast, and the right the landward side, or that to the northwest.

3. The flexures are most numerous and most crowded on that side of the Appalachian region which is *toward the ocean*, and diminish westward. There is seldom, however, a gradual dying out westward, the region of disturbance being often bounded on the west by one or more of the great fractures and faults, as in Eastern Tennessee and along the valley of the Hudson.

4. The consolidation and metamorphism of the strata are more extensive and complete to the eastward (or toward the ocean) than to the westward.

5. The change of bituminous coal to anthracite, by the expulsion of volatile ingredients, was most complete where the disturbances were greatest, — that is, in the more eastern portions of the coal areas. The anthracite region of Pennsylvania (see map, p. 242) owes its broken character partly to the uplifts and partly to denudation. To the westward the coal is first semi-bituminous, and then, as at Pittsburg, true bituminous. In Rhode Island, where the associated rocks are partly true metamorphic or crystalline rocks and the disturbances are very great, the coal is an extremely hard anthracite, and in some places is altered to graphite, — an effect which may be produced in ordinary coal by the heat of a furnace.

7. Conclusions. — These facts lead to the following conclusions: —

1. The movement producing these vast results was due to lateral pressure, the folding having taken place just as it might in paper or cloth under a lateral or pushing movement.

2. The pressure was exerted at right angles to the courses of the folds, as is the case when paper is folded in the manner mentioned.

3. The pressure was exerted *from* the ocean side of the Appalachians; for the results in foldings and metamorphism are most marked toward the ocean.

4. The force was vast in amount.

5. The force was slow in action and long continued, — and not abrupt or paroxysmal as when a wave or series of waves is thrown up by an earthquake shock on the surface of an ocean. For the strata were not reduced by it to a state of chaos, but retain their stratification, and show comparatively little confusion, even in the regions of greatest disturbance and alteration.

6. The action of the force was attended by the production of heat. For without some heat above the ordinary temperature, it is not possible to account for the consolidation and crystallization of the rocks.

7. The history of the Appalachian Mountains extends through all the geological ages from the Archæan onward. During the Silurian, Devonian, and Carboniferous ages the formations were accumulating to a great thickness, while a slow subsidence was in progress. When the Carboniferous age was closing, and the subsidence had reached a depth of several miles, there were other movements, producing flexures of the strata, uplifts, faults, consolidation, and metamorphism, and ending in the making of the mountains. And finally, during these upliftings, moving waters commenced the work of denudation, which has been continued to the present time.

8. **Disturbances on other continents.** — The amount of contemporaneous mountain-making over the globe at this epoch has not yet been clearly made out. Enough is known to render it probable that the Ural Mountains, with their veins of gold and platinum, were made at the same time with the Appalachians, and that uplifts and metamorphism also occurred in other parts of Europe, and in Great Britain. Murchison states that the close of the Carboniferous period was specially marked by disturbances and uplifts; that it was then “that the coal strata and their antecedent formations were very

generally broken up, and thrown, by grand upheavals, into separate basins, which were fractured by numberless powerful dislocations."

The epoch of the Appalachian revolution was, then, a grand epoch for the world. The extermination of life which took place at the time was one of the most extensive in all geological history, and must have been a consequence of the great physical changes progressing over the earth's surface. But it cannot be affirmed that the extermination was universal, although no fossils of the Carboniferous formation occur in later rocks; for these strata, as they are confined to portions of the continental seas, testify only as to changes and destructions throughout those seas, and not respecting the life existing elsewhere.

III. — MESOZOIC TIME.

1. **Ages.** — Mesozoic or mediæval time, in Geological history, comprises but one age, — the REPTILIAN. In the course of it the class of Reptiles passed its culmination; — that is, its species increased in numbers, size, and diversity of forms, until they vastly exceeded in each of these respects the Reptiles of either earlier or later time.

2. **Area of progress in rock-making.** — The area of rock-making in North America, during Mesozoic time, was somewhat different from what it was in Paleozoic. Then, nearly the whole continent, outside of the northern Archæan area, was receiving its successive formations; and the three great regions were the *Eastern border*, the *Appalachian*, and the *Interior Continental*. By the close of Paleozoic time the Appalachian region and the Interior east of the Mississippi, excepting its southern portion, had become part of the dry land of the continent, as is shown by the absence of marine strata of later date. The great areas of progress were conse-

quently changed, and became (1) the *Atlantic border*, (2) the *Gulf border*, and (3) the *Western Interior*, or region west of the Mississippi. In other words, the continent, from the Mesozoic onward, until the close of the Tertiary period in the Cenozoic, was receiving its new marine formations along its borders, and in extensive areas over the part of the Interior region embraced by the Summit region and slopes of the Rocky Mountains.

These three regions are continuous with one another, the Atlantic connecting with the Gulf border region on the south, and the Gulf border region passing northwestward into the Western Interior or Rocky Mountain region and Pacific border.

In Europe no analogous change can be distinguished ; for the continent was, from the first, an archipelago, and it continued to bear this geographical character, though with an increasing prevalence of dry land, until the Cenozoic era had half passed. Western England then stood as three or four islands above the sea (the area marked as covered by Paleozoic rocks on the map, page 244) ; and the area of future rock-making was mainly confined to the intervals between these islands and to the submerged area on the east and southeast. It is probable that this area and a portion of Northeastern France were, geologically, part of a large German-Ocean basin.

REPTILIAN AGE.

Periods. — The Reptilian Age includes three periods : —

1. *Triassic* : named from the Latin *tria*, *three*, in allusion to the fact that the rocks of the period in Germany consist of three separate groups of strata. This is a local subdivision, not characterizing the rocks in Britain or in most other parts of Europe.

2. *Jurassic* : named from the Jura Mountains, situated on the eastern border of France, between France and Switzerland, where rocks of the period occur.

3. *Cretaceous*: named from the Latin *creta*, *chalk*, the chalk-beds of Britain and Europe being included in the Cretaceous formation.

1. Triassic and Jurassic Periods.

1. Rocks: Kinds and Distribution.

The American rocks of the Triassic period have not yet been separated from those of the Jurassic, except in the region west of the Mississippi.

In the *Atlantic-border* region these rocks occupy narrow ranges of country parallel with the Appalachian chain, following its varying courses. One of these ranges occupies the valley of the Connecticut between Northern Massachusetts and New Haven on Long Island Sound, and runs parallel with the Green Mountains: it has a length of about 110 miles. Another — the longest of them — commences at the north extremity of the Palisades, on the west bank of the Hudson River, and stretches southwestward through New Jersey, Pennsylvania (here bending much to the westward, like the Appalachians of the State, as shown in the map on page 242), and reaching far into the State of Virginia. Another stretches — almost in the line of the last — through North Carolina. There is another along Western Nova Scotia. These, and some other smaller areas, are indicated on the map on page 195 by an oblique lining in which the lines run from the right above to the left below.

The rocks are mainly sandstones and conglomerates, but include some considerable beds of shale, and in a few places impure limestone. The sandstones are generally red or brownish-red. The *freestone* of Portland, near Middletown in Connecticut, and of the vicinity of Newark in New Jersey, are from this formation. The pebbles and sand of the beds were derived mainly from metamorphic rocks alongside of the regions in which they lie; and from some of the coarser layers large stones of granite, gneiss, and mica schist

may be taken. The strata overlie directly, but *unconformably*, these metamorphic rocks. Near Richmond in Virginia and in North Carolina there are valuable beds of bituminous coal.

The several ranges of this sandstone formation are remarkable for the great number of trap dikes and trap ridges intersecting them (page 43). Mount Holyoke in Massachusetts, East and West Rocks near New Haven in Connecticut, and the Palisades on the Hudson are a few examples of these trap ridges. Trap is an igneous rock, one that was ejected in a melted state from a deep-seated source of fire, through fissures made by a fracturing of the earth's crust. The dikes and ridges are exceedingly numerous, and have the same general course with the sandstone ranges. They are so associated with the sandstone formation that there must have been some connection in origin between the water-made and the fire-made rocks. The proofs that the trap came up through the fissures in a melted state are abundant; for the wall-rock of the fissures is often baked so as to be very hard, and is sometimes filled with crystallizations, as of epidote, tourmaline, garnet, hematite, etc., evidently due to the heat.

West of the Mississippi, in the Western Interior region southwest of Southern Kansas, there is a sandstone formation, containing much gypsum (and hence called the *gypsiferous formation*), but barren of fossils, except an occasional fragment or trunk of fossil wood, which is regarded as Triassic. Triassic beds occur also in Colorado and New Mexico, Utah and Nevada. Along with Jurassic strata they enter into the constitution of the Elk and Wahsatch mountains, and the Sierra Nevada. These western Jurassic beds in many places contain fossils, but only rarely so the Triassic.

In the vicinity of the Black Hills, in the region of the Upper Missouri, there are some beds of impure limestone containing marine fossils which are true Jurassic.

In *Europe*, the Triassic rocks of Eastern France and Germany, east and west of the Rhine, consist of a shell limestone

(called in German *Muschelkalk*) between an underlying thick reddish sandstone (*Bunter Sandstein*) and overlying strata of reddish and mottled marlytes and sandstone (*Keuper* of the Germans). In *England* (see No. 6 on map, page 244), the formation consists of reddish sandstone and marlytes; it is mostly confined to a region running north-northwest just east of the Paleozoic areas, and to an extension of this region westward to Liverpool bay (or over the interval between the two main areas) and up the west coast.

This formation, in Europe, contains in many places beds of salt, and is hence often called the *Saliferous group*. At Northwich in Cheshire, in England, there are two beds of rock-salt, 90 to 100 feet thick; and in Europe there are similar beds at Vic and Dieuze in France, and at Wurtemberg in Germany.

The Jurassic rocks of Britain and Europe are divided into three principal groups:—

1. The *Liassic* (No. 7a on map of England, page 244), consisting of grayish compact limestone strata, called *Lias*.

2. The *Oölytic* (No. 7b on map, page 244), consisting mostly of whitish and grayish limestones, part of them oölitic (page 37). One stratum, near the middle of the series, is a coral-reef limestone, much like the reef-rock of existing coral seas, though different in species of coral. Near the top of the series there are some local beds of *fresh-water* or *terrestrial* origin, in what is called the Purbeck group, and one on the island of Portland is named, significantly, the *Portland dirt-bed*. The Solenhofen lithographic limestone is a very fine-grained rock (thereby fit for lithography), of the age of the Middle Oölyte occurring in Pappenheim in Bavaria.

3. The *Wealden* (No. 8 on the map of England), a series of beds of estuary and fresh-water origin, mostly clay and sand, but partly of limestone. They occur in Southeastern England. They are named *Wealden* from the region where first studied, called the *Weald*, covering parts of Kent, Surrey, and Sussex.

2. Life.

1. Plants.

The vegetation of the Triassic and Jurassic periods included numerous kinds of *Ferns*, both large and small, *Calamites*, and *Conifers*, and so far resembled that of the Carboniferous age. But there were no forests or jungles of *Lepidodendrids* and *Sigillarids*. Instead of these Carboniferous types, a group of trees and shrubs sparingly represented in the later Carboniferous, that of the *Cycads*, was eminently characteristic of the Mesozoic world. This group has now but few living

species, and among the genera, *Cycas* and *Zamia* are those whose names are best known. The plants have the aspect of Palms; and

Fig. 316.



Fig 316 a.

CYCADS: Fig. 316, *Cycas circinalis* ($\times \frac{1}{120}$); 316a, leaf of a living *Zamia* ($\times \frac{1}{10}$).

there was, therefore, in the Mesozoic forests a mingling of palm-like foliage with that of Conifers (Spruce, Cypress, and the like). But the Cycads are not true Palms. They are

Gymnosperms, like the Conifers both in the structure of the wood and in the fruit. The resemblance to Palms is mainly in the cluster of great leaves at the summit, and in the appearance of the exterior of the trunk. Fig. 316 represents, much reduced, a modern *Cycas*, and 316 *a* the leaf of a living *Zamia*, one twentieth the actual length. The fossil remains of Cycads are either their trunks or leaves. A fossil species from the Portland dirt-bed is represented in Fig. 317. The trunks of some Cycads have a height of 15 or 20 feet. In one important respect these Cycads resemble the Ferns,—that is, in the unfolding of the young

Fig. 317.



Stump of the Cycad, *Mantellia*
(*Cycadeoidea*) *megalophylla*
($\times \frac{1}{12}$).

Figs 318-322.

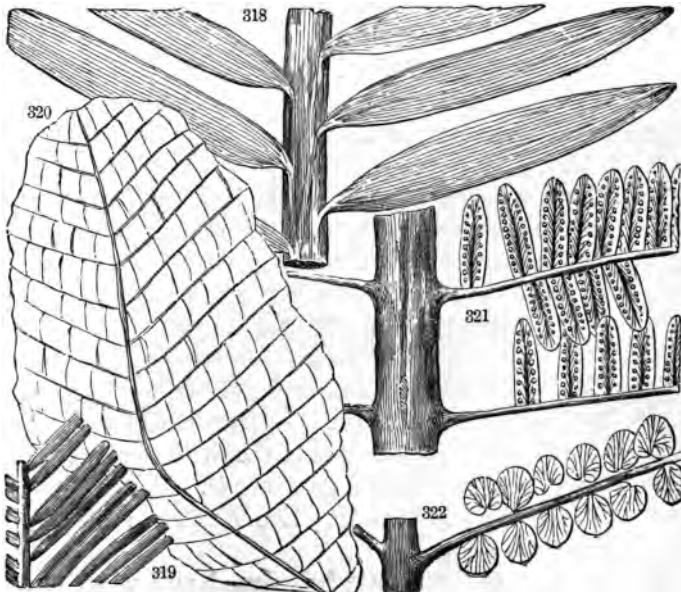


Fig. 318, *Podozamites lanceolatus*; 319, *Pterophyllum graminoides*; 320, *Clathropteris rectiusculus*; 321, *Pecopteris* (*Lepidopteris*) *Stuttgartensis*; 322, *Cyclopteris linnaefolia*.

leaf,—the leaf being at first rolled up into a coil, and gradually unrolling as it expands. The Cycads thus combine peculiarities of three orders of plants,—Ferns, Palms, and Conifers,—and are examples, therefore, of what are called *comprehensive* types.

Fossil plants are common in the coal-regions of Richmond, Virginia, and in North Carolina, and occur also in other localities. Figs. 318, 319 are parts of the leaves of two species of Cycads, from North Carolina. Figs. 320 to 322 represent a few of the ferns: Fig. 320, a *Clathropteris*, from East Hampton, Mass.; Fig. 321, a *Pecopteris*, from Richmond, Va., and the Trias of Europe; Fig. 322, a *Cyclopteris*, from Richmond, Va. Large cones of firs have also been found. Several of the American plants are identical in species with those of the European Triassic, and a few nearer to Jurassic forms.

2. Animals.

a. American.

The American beds of the *Atlantic border* region are remarkable for the *absence of true marine* life: all the species appear to be either those of brackish water, or of fresh water, or of the land.

1. **Radiates and Mollusks.**—In the beds of the Atlantic border Radiates are unknown; and the remains of *Mollusks* are of doubtful character. The Jurassic beds of the Rocky Mountain region and its western borders contain many species, and the Triassic of California a few.

2. **Articulates.**—The shells of *Ostracoid Crustaceans* are common in New Jersey, Pennsylvania, Virginia, and North Carolina, but have not yet been found in New England. Fig. 323 represents one of the little shells of these bivalve species, called an *Estheria*. It was long supposed to be Molluscan. The *Estheriæ* are brackish-water species.

Fig. 323.



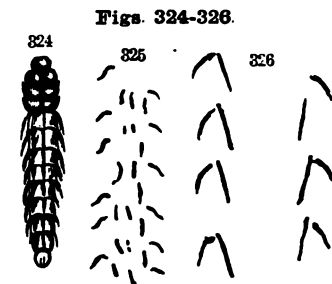
Estheria
ovala.

A few remains of *Insects* have been found, and, what is more remarkable, the tracks of several species. These tracks were

made on the soft mud, probably by the larvae of the Insects, for certain kinds pass their larval state in the water. Fig. 324 represents one of these larvae found in shale at Turner's Falls in Massachusetts; it resembles, according to Dr. Le Conte, the larve of a modern *Ephemera*, or May-fly. Figs. 325, 326 are the tracks of Insects. Professor Hitchcock has named nearly 30 species of tracks of Insects and Crustaceans.

3. **Vertebrates.** — There are evidences of the existence of *Fishes*, *Reptiles*, *Mammals*, and probably *Birds*. With the appearance of the last two types the sub-kingdom of Vertebrates

was finally represented in all its



ARTICULATES. — Fig. 324, *Palephemera mediaeva* ($\times 1\frac{1}{2}$); 325, 326, Tracks of Insects.

1. The *Fishes* found in the American rocks are all *Ganoids*, although *Selachian* remains are common in Europe. Fig. 327 represents one of the species, reduced one half; the tail is half vertebrated. In other species of these rocks it is not at all vertebrated, being like that of modern Ganoids; and in them this old paleozoic feature of the Ganoids is finally lost.

Fig. 327.

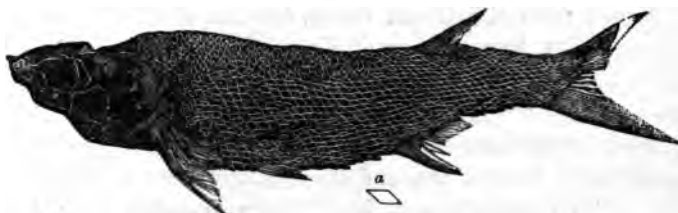
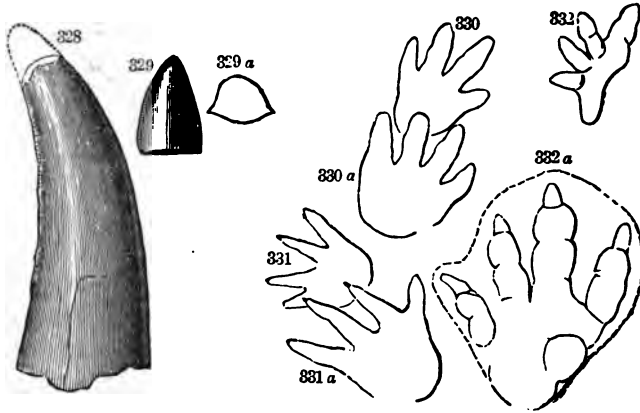


Fig. 327, GANOID, *Catopterus gracilis* ($\times \frac{1}{2}$); a, Scale of same, natural size.

2. *Amphibians*, of the tribe of *Labyrinthodonts* (page 257), appear to have reached their greatest size and numbers in the Triassic period. A foreign species is mentioned on page 300.

Footprints of the Connecticut valley beds appear to indicate the existence of American species. Figs. 330, 330 *a*, and 331, 331 *a* represent tracks of two of these. But among the kinds

Figs. 328-332.



REPTILES. — Fig. 328, *Bathygnathus borealis* ($\times \frac{1}{2}$); 329, *Belodon priscus*; 329 *a*, section of same; 330, 330 *a*, fore and hind feet of *Anisopus Deweyanus* ($\times \frac{1}{2}$); 331, 331 *a*, *ibid.* of *A. gracilis* ($\times \frac{1}{2}$); 332, 332 *a*, *ibid.* of *Otozoum Moodii* ($\times \frac{1}{4}$).

so referred some were biped in locomotion; and these, according to Marsh, were probably Dinosaurs, as described below.

3. *True Reptiles*. — 1. **Dinosaurs**. — The Dinosaurs were so named from the Greek *δεινός*, *terrible*, and *σαῦρος*, *lizard*, some species being of great size. They were the leading life of North America in Triassic and Jurassic time. In the East they are known from the thousands of footprints left by them in the Connecticut valley and New Jersey, and to a small extent from bones, and these chiefly from Pennsylvania and North Carolina; and in Western America from huge skeletons found in the Rocky Mountain region. Many, as the tracks show, were *biped* in locomotion, while others were *quadruped-like*. The bipeds were of two tribes. In one, the animals made 3-toed *bird-like* tracks, as in Figs. 333, 334; in the other, broad 4-toed or 5-toed tracks, as in

Fig. 332 *a* (Fig. 332 being the corresponding fore-foot). The track represented in Fig. 333 is actually *eighteen* inches long, and that of Fig. 332 *a*, *twenty* inches; and probably each of these biped Dinosaurs stood over twenty feet high. Some of the 3-toed tracks are accompanied by *impressions of fore-feet*, proving that the animals were not birds, and rendering it probable that none were so. The biped march of these species is a bird-like characteristic, and it is connected with a more or less bird-like pelvis, and sometimes with hollow bones. Fig. 328 represents a tooth of a Dinosaur from Prince Edward's Island.

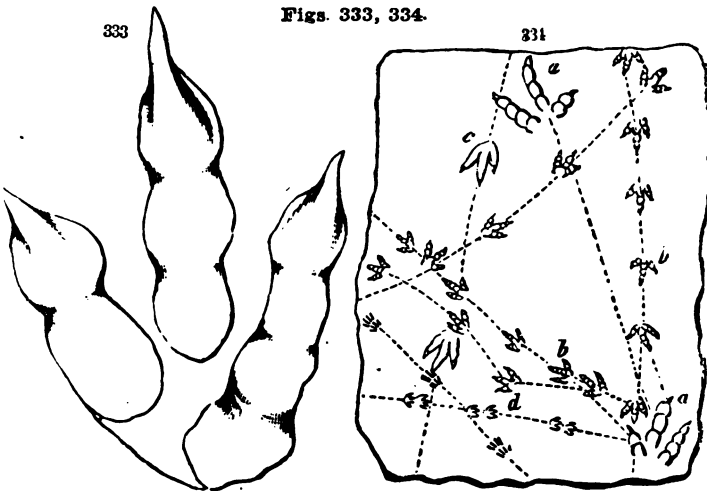


Fig. 333, Track of *Brontozoum giganteum* ($\times \frac{1}{2}$); 334, Slab of sandstone with tracks of Birds? and Reptiles ($\times \frac{1}{16}$).

Jurassic Dinosaurs of enormous size have been described by Marsh from beds in Wyoming and Colorado. One named by him, *Atlantosaurus*, had the thigh bone over 6 feet long, and a length of body of probably 60 feet, showing a magnitude before thought impossible in a terrestrial animal.

2. **Lacertians, or Lizard-like species.** — Fig. 329 represents a tooth from North Carolina referred to a Lacertian called *Belodon priscus*.

3. **Enaliosaurus.** — Found in the Triassic of Nevada.

4. **Mammals.**—In the North Carolina Triassic have been found two jaw-bones (Fig. 335) of a species of *Marsupial*—the division of Mammals to which the modern Opossum of the same region belongs. Several other Marsupials have been described by Marsh from Jurassic beds in Wyoming and Colorado.

Fig. 335.

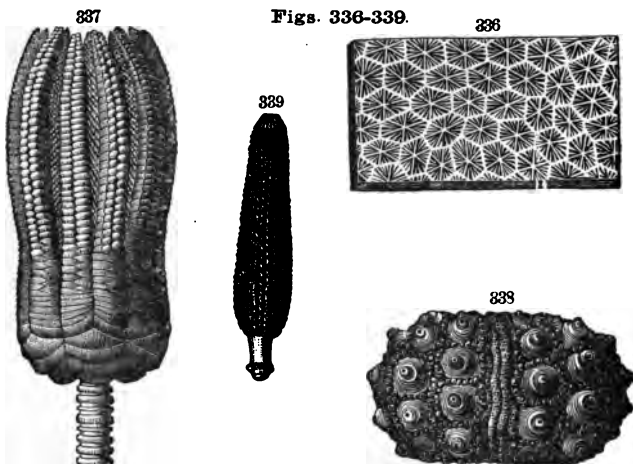
Jaw-bone of *Dromatherium sylvestre*.

The facts prove that the land population of Mesozoic America included *Insects*, *Amphibians*, *Reptiles*, and *Marsupial Mammals*; and that the forests which covered

the hills were mainly composed of *Conifers* and *Cycads*. *Birds* may have been present also: for (1) remains of true Birds have been found in the Jurassic of Europe; (2) it seems hardly probable that Mammals should have preceded Birds; and (3) Birds, because terrestrial and of slender bones, are the least likely of species to be preserved.

b. Foreign.

The European and British rocks of these periods, especially



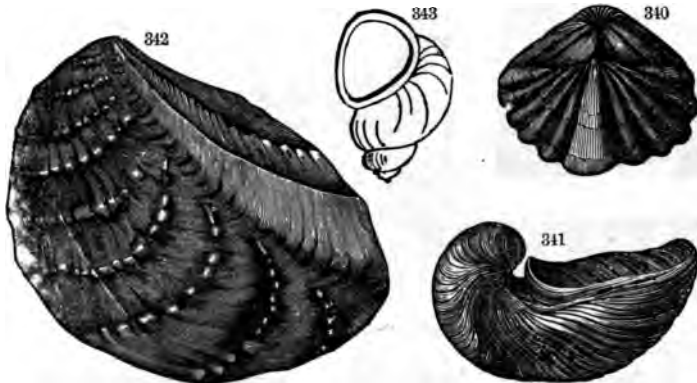
RADIATES: Fig. 336, *Prionastræa oblonga* (a Coral); 337, *Enerinus liliiformis* (a Crinoid); 338, *Cidarid Blumenbachii* (an Echinus); 339, Spine of same.

of the Jurassic, abound in marine fossils, and afford a good idea of the Mesozoic life of the ocean. The remains of terrestrial life are also of great interest, Marsupial Mammals occurring in the Triassic beds, and birds in the Jurassic.

1. **Radiates.** — Polyp-corals are common in some Jurassic strata: they are related to the modern tribe of corals, and not to the ancient. Fig. 336 represents one of the Oölytic species. Crinoids are of many kinds, yet their number, as compared with other fossils, is far less than in the preceding ages; and they are accompanied by various new forms of *Star-fishes* and *Echini* (page 183). Fig. 337 represents one of the Triassic Crinoids, the *Lily-Encrinite*, or *Encrinurus liliiformis*; Fig. 338, an *Echinus*, from the Oölyte, stripped of its spines; and Fig. 339, one of the spines separate.

2. **Mollusks.** — *Brachiopods* are few compared with their number in the Paleozoic. The last species of the Paleozoic genera, *Spirifer* and *Leptaena*, lived in the early part of the

Figs. 340-343.



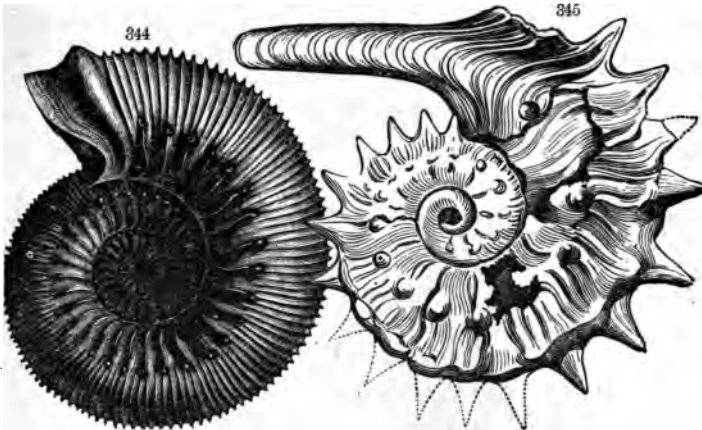
MOLLUSKS: Fig. 340, *Spirifer Walcottii*; 341, *Gryphæa incurva*; 342, *Trigonia clavellata*; 343, *Viviparus (Paludina) fluviorum*.

Jurassic period. Fig. 340 represents one of these last of the *Spirifer* group. *Lamellibranchs* and *Gasteropods* abound in species, and under various new, and many of them modern, genera.

Species of the genus *Gryphæa* were common in the Lias and later Mesozoic rocks: they are related to the Oyster, but have the beak incurved. Fig. 341 represents a Liassic species. *Trigonia* (Fig. 342) is a characteristic genus of the Mesozoic; the name alludes to the triangular form of the shell: the species figured is from the Oölyte. Fig. 343 represents a fresh-water snail-shell, a very abundant fossil in the fresh-water limestone of the Wealden, closely resembling many modern species.

But the most remarkable and characteristic of all Mesozoic Mollusks were the *Cephalopods*. This order passed its maximum as to number and size in the Mesozoic, and hundreds of species existed. The last of the Paleozoic types of *Orthocerata*

Figs. 344, 345.



MOLLUSKS: Fig. 344, *Ammonites Humphreysianus*; 345, *A. Jason*.

and *Goniatites* lived in the Triassic period. In the same period species of *Ammonites*, one of the most characteristic of Mesozoic groups, became common; and, in the earliest Jurassic, the first of *Belemnites*, another peculiarly Mesozoic type, appeared.

The *Ammonites* had *external chambered* shells like the *Nau-*

tili (page 181) and *Goniatites*. Two Oölytic species are represented in Figs. 344, 345. One of them (Fig. 345) has the side of the aperture very much prolonged; but the outer margin of the shell, whether prolonged or not, is seldom well preserved. The partitions (or septa) within the shells of *Ammonites* are bent back in many folds (and much plaited within each fold) at their junction with the shell, so as to make deep plaited pockets. The front view of the outer plate, with the entrances to its side-pockets, are seen in Fig. 346. The fleshy mantle of the animal descended into these pockets, and thus the animal was aided in holding firmly to its shell. The siphuncle in the *Ammonites* is dorsal. The Paleozoic *Goniatites* were of the Ammonite family, but the pockets were much more simple, the flexures of the margins of the partitions being without plications.

Fig. 346.

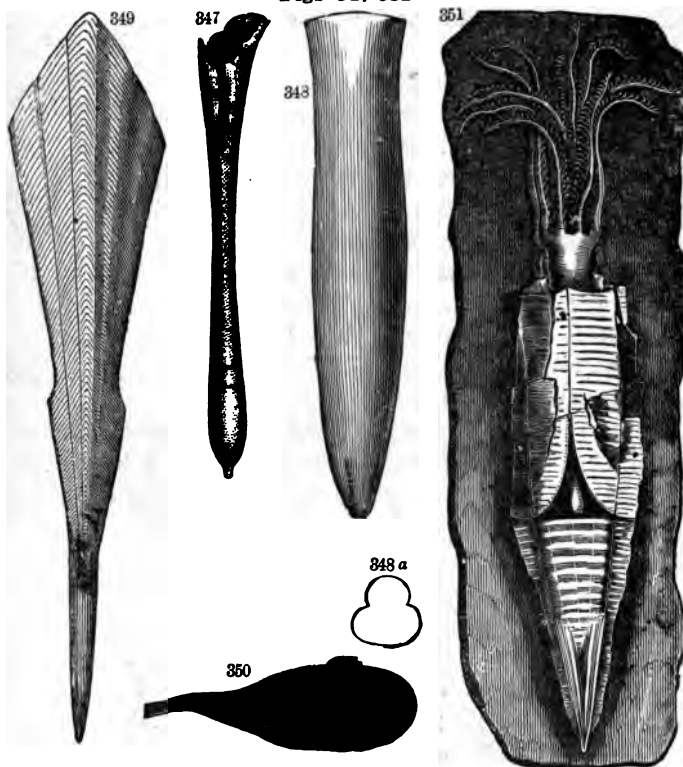
*Ammonites tornatus.*

The fossil *Belemnite* is the *internal* bone of a kind of *Cephalopod*, analogous to the pen or internal bone (or osselet) of a *Sepia*, or *Cuttle-fish* (see Fig. 351). It is a thick, heavy fossil, of the forms in Figs. 347, 348, having a conical cavity at the upper end. The fossils are more or less broken at this extremity; when entire, the margin of the aperture is elongated into a thin edge, and sometimes, on one side, into a thin plate of the form in Fig. 349. The animal had an ink-bag like the modern *Sepia*; and ink from these ancient Cephalopods has been used in sketching their fossil remains. Fig. 350 represents one of the ink-bags of the Jurassic Cephalopods. Fig. 351 is another related Cephalopod, showing something of the form of the animal, and also the ink-bag in place.

3. **Articulates.**—The Articulates included various shrimps, or craw-fishes (Fig. 352, a Triassic species), Crabs, and Tetracephalopod (or 14-footed) Crustaceans (Fig. 353, representing a species something like the modern *Sow-bug*), but no *Trilobites*; also Spiders (Fig. 354), and species of many of the

orders of Insects. Fig. 355 is a *Libellula*, or *Dragon-fly*, of the Jurassic period, from Solenhofen ; and Fig. 356, the wing-case of a beetle, from the Stonesfield Oölyte.

Figs. 347-351.

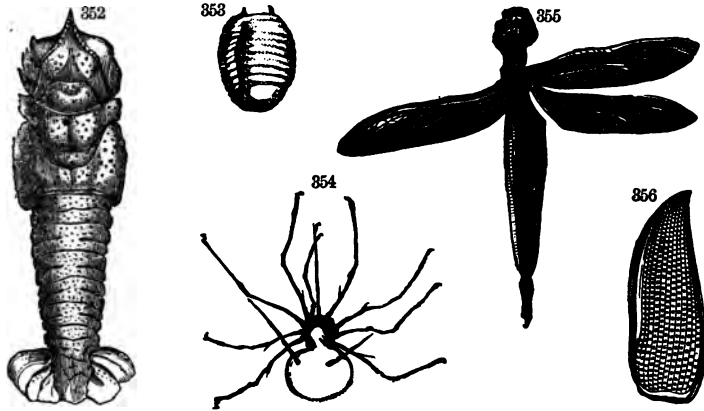


MOLLUSKS : Fig. 347, *Belemnites clavatus* ; 348, *B. paxillosus* ; 348 a, Outline of section of same, near extremity ; 349, View, reduced, of the complete osselet of a Belemnite ; 350, Fossil ink-bags of a Cephalopod ; 351, *Acanthoteuthis antiquus*.

4. Vertebrates.—The *Fishes* were chiefly *Ganoids* or *Selachians*. In the Triassic beds of Europe, as in America, occurred the *last* species of the *vertebrated-tailed* Ganoids, and the *first* of those having the tail not vertebrated. Fig. 357 represents one of the latter kind from the Lias. Among the

Sharks (or *Selachians*) the *Cestraciont* tribe, one of the most ancient, characterized by a pavement of grinding teeth (page

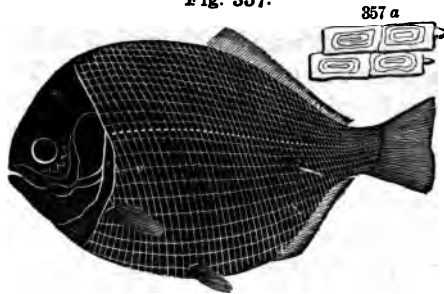
Figs. 352-356.



ARTICULATES: Fig. 352, *Pemphix Sueurii*; 353, *Archæoniscus Brodiei*; 354, *Palpipes priscus*; 355, *Libellula*; 356, Wing-case of a *Buprestis*.

178), still continued, and was very numerous represented. There were also, in the Jurassic beds, *Sharks* having sharp-

Fig. 357.



VERTEBRATE: Fig. 357, Restored figure of *Æchmodus* (*Tetragonolepis*) from the Lias ($\times \frac{1}{2}$); 357 a, Scales of same.

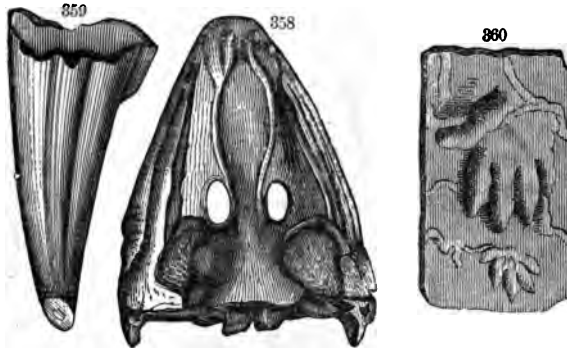
edged teeth like those of the tribe of *Sharks* that inhabits modern waters.

The genus *Ceratodus*, represented by species in the Trias,

has living species in Australia ; and they are Ganoids, related to the modern *Dipnoans*, or fishes that, like the *Lepidosiren*, have both gills and lungs.

Amphibians were common in the European Trias, as in the American, and some were of gigantic size.

Figs 358-360.



VERTEBRATES : Fig. 358, Skull of *Mastodonsaurus giganteus* ($\times \frac{1}{12}$); 359, Tooth of same ($\times \frac{1}{4}$); 360, Footprints of *Cheriotherium* ($\times \frac{1}{12}$).

Among the Triassic Amphibians, one frog-like *Labyrinthodont* had a skull over 2 feet long, of the form shown in Fig. 358 ; its mouth was set round with teeth 3 inches long (Fig. 359), and the body was covered with scales. The specimen here figured was found in Saxony. It is probable that some of the American Reptilian species whose tracks are so common in the Connecticut Valley were of this type. Fig. 360 is a reduced view of hand-like tracks, from the same locality as the above, supposed to have been made by an animal of the same species. The frogs of the present day are feeble and diminutive compared with the Triassic Amphibians.

The *True Reptiles* included species for each of the elements, — the water, the earth, the air.

Among them there were, first, *Swimming Reptiles*, — called *Enaliosaurs* because they belonged especially to the sea (from the Greek *ἐνάλιος*, of the sea, and *σαῦρος*, lizard) ; they prob-

ably existed in the Carboniferous age (page 258), but became numerous and of great size in the Middle Mesozoic. They had paddles like Whales, and thus were well fitted for marine life. The most common kinds were the *Ichthyosaurs* and *Plesiosaurs*.

Figs. 361-365.



VERTEBRATES : Fig. 361, *Ichthyosaurus communis* ($\times \frac{1}{10}$); 362, Head of same ($\times \frac{1}{10}$); 363 a, 363 b, View and section of vertebra of same ($\times \frac{1}{4}$); 364, Tooth of same, natural size; 365, *Plesiosaurus dolichodeirus* ($\times \frac{1}{10}$); 365 a, 365 b, View and section of vertebra of same.

The *Ichthyosaurs* (Fig. 361) had a short neck, a long and large head, enormous eyes, and thin, doubly-concave, and therefore fish-like, vertebræ. The name is from the Greek *ἰχθύς*, *fish*, and *σαῦρος*, *lizard*. Fig. 362 represents the head of an *Ichthyosaur*, one thirtieth the natural length, showing the large size of the eye and the great number of the teeth. Fig. 363 b is one of the vertebræ, reduced, and Fig. 363 a, a transverse section of the same, exhibiting the fact that both surfaces are deeply concave, nearly as in fishes; Fig. 364 is one of the teeth, natural size. Some of the *Ichthyosaurs* were 30 feet long.

The *Plesiosaurs* (named from the Greek *πλησίος*, *near*, and *σαῦρος*, because not quite like a Saurian), one of which is represented very much reduced in Fig. 365, had a long snake-like neck, a comparatively short body, and a small head. Fig. 365 *a* represents one of the vertebræ, and 365 *b*, a section of the same; it is doubly concave, but less so, and much thicker, than in the *Ichthyosaurs*. Some species of *Plesiosaur* were 25 to 30 feet long. Another related Reptile, called a *Phiosaur*, was 30 to 40 feet long. Remains of more than 50 species of *Enaliosaur*s have been found in the Jurassic rocks.

Besides these swimming Saurians, there were numerous species of *Lacertians* (*Lizards*) and *Crocodylians* 10 to 50 feet long, and *Dinosaurs*, the bulkiest and highest in rank of the Saurians, 25 to 60 feet long.

To the group of Dinosaurs belongs the *Iguanodon*, of the Wealden beds, first made known by Dr. Mantell, whose body was 28 to 30 feet long, and which stood high above the ground quadruped-like, the femur, or thigh-bone, alone being nearly 3 feet long. The hind feet were three-toed like those of birds. Its habits are supposed to have been like those of the ancient sloth-like animal called a *Megatherium* (page 365), —the animal grazing on the trees along the borders of the marshes, estuaries, or streams in or about which it lived, and able to lift its body on its hind legs for this purpose. It had teeth like the modern *Iguana*, (and hence the name, from *Iguana*, and the Greek *ὀδούς*, *tooth*), but it had proportionately a much shorter tail. The *Megalosaur* was another of the gigantic Dinosaurs of the later part of the Jurassic period; it was a terrestrial carnivorous Saurian about 30 feet in length, and was better fitted in its limbs for raising its body toward an erect posture. The three-toed American Reptiles, whose tracks are described on page 293, are those of other Dinosaurs; and these had the habit of bipeds. Many points in the structure of the limbs and pelvis of the Dinosaurs are similar to those of birds.

The Reptiles adapted for the air — that is, for flying — are

designated *Pterosaurs*, from the Greek πτερόν, *wing*, and σαῦρος. The most common genus is called *Pterodactylus*. The general form of a *Pterodactyl* is shown in Fig. 366. The bones of one of the fingers are greatly elongated, for the purpose

Fig. 366.

VERTEBRATE. — *Pterodactylus crassirostris* ($\times \frac{1}{2}$).

of supporting an expanded membrane, so as to make it serve (like an analogous arrangement in bats) for flying. The name *Pterodactyl* is from the Greek πτερόν, *wing*, and δακτύλος, *finger*. The Jurassic *Pterodactyls* were mostly small, and probably had the habits of bats; the largest had a spread of wing of about 10 feet. Unlike our common birds, they had a mouth full of teeth, and no feathers. As Bats are flying Mammals, so the *Pterosaurs* are simply flying Reptiles, and have little resemblance to birds in structure, except that their bones are hollow, and adapted in form for the bird-like characteristic of flying.

Besides the kinds of Reptiles already mentioned, there were *Turtles* in the Jurassic period; but, according to present knowledge, the world contained *no true Snakes*.

Coprolites (or fossil excrements) of both Reptiles and Fishes are common in the bone-beds. When cut and polished they

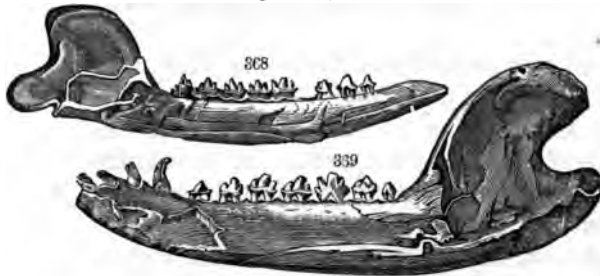
Fig. 387.

VERTEBRATE. — The bird, *Archæopteryx macrura*.

have a degree of beauty sufficient to give them some value in jewelry.

Remains of *Birds* have been found in the quarries of Solenhofen (page 287). They have revealed the fact that some at least of the Mesozoic Birds (and of America, beyond question, as well as Europe) were *reptilian* in some of their characters. The skeleton found (Fig. 367) shows that the Birds had long reptile-like tails consisting of many vertebræ, and finger-like claws on the fore limb or wing, like those of the *Pterodactyl* and *Bat*, fitting them evidently for clinging. But, while thus reptilian in some points of structure, they were actually *Birds*, being feathered animals, and having the expanse of the wing made, not by an expanded membrane as in the *Pterodactyl*, but by long quill-feathers. The tail-quills were

Figs 368, 369.



VERTEBRATES. — Fig. 368, *Amphitherium Broderipii* ($\times 2$); 369, *Plascolotherium Bucklandi* ($\times 2$).

arranged in a row either side of the long tail. The feet were like those of birds.

Remains of *Mammals* occur in the Upper Trias (or base of the Lias) of Germany, in the Lower Oölyte deposit at Stonesfield, England, and in the Middle Purbeck beds of the Upper Oölyte (page 287). Nearly 20 species have been made out, 14 of them from relics in the Middle Purbeck. The larger part, if not all, are *Marsupials*. Figs. 368, 369 represent the jaws of two species from Stonesfield, magnified twice the natural size.

As Marsupials are semi-oviparous Mammals, and therefore are intermediate between ordinary Mammals and the inferior and oviparous Vertebrates (page 176), it follows that both the *Birds* and *Mammals* of the Mesozoic were *in part*, at least, *comprehensive* or *intermediate* types, and partook of *reptilian* features in the Reptilian age.

3. General Observations.

1. **American Geography.**—The Triassic-Jurassic sandstones and shales of the Atlantic border region are sedimentary beds; consequently, the long narrow ranges of country in which they were formed were occupied at the time more or less completely by water.

The absence of true marine fossils has been remarked upon as proving that this water was either brackish or fresh; and hence the areas were estuaries or deep bays running far into the land.

There was probably an abundance of marine life in the ocean, if we may judge from its diversity on the other side of the Atlantic; but the sea-coast of the era must have been outside of the present one, so that any true marine or sea-coast deposits that were made are now submerged. The present sea-border is shallow for a distance of 80 miles from the New Jersey coast, the depth of water at this distance out being but 600 feet. (See map, page 12.)

As all the depressions or valleys occupied by the estuaries are parallel with the Appalachians (page 285), and since the era of the formations was that next following the origin of these mountains, the depressions were probably made at the time the Appalachian foldings were in progress, or are great valleys or depressions then left in the surface.

The level of the several sandstone areas above the ocean proves that the land at the time was not far from its present elevation, and therefore that the Appalachians had probably nearly their present height.

The deposits contain footprints, ripple-marks, rain-drop

impressions, and other evidences, on many of the layers, that they were formed partly in shallow waters, and partly as sand-flats, or emerging marshes and shores, over which reptiles and birds might have walked or waded. If, then, they are several thousands of feet thick, there must have been a progressing subsidence of the valley-depressions, — that is, a sinking must have been going on. It is hence apparent that oscillations of level, like those that characterized the Appalachian region before and during the Appalachian revolution, were in progress. Two effects of this subsidence occurred : (1) The sandstone beds were more or less faulted and tilted, those of the Connecticut Valley receiving a dip to the eastward, or southeastward, those of New Jersey and Pennsylvania to the northwestward. (2) In the sinking of the valley-depression, an increasing strain was produced in the earth's crystalline crust beneath, which finally became so great that the crust broke, fissures opened, and liquid rock came up. The dikes and ridges of trap are this liquid rock solidified by cooling. The existence of the dikes, and their parallelism to the general course of the valley-depressions, prove — (1) the fact of the fractures ; (2) their resulting from the same cause which produced the sinking ; and (3) the fact of the igneous ejections. The earth's crust along the Connecticut Valley was thus a scene of igneous operations for more than 100 miles, and through a vast number of opened fissures. All the Triassic-Jurassic areas from Nova Scotia to Southern North Carolina, a distance of 1,000 miles, were similarly broken through and invaded by trap ejections. The Palisades of the Hudson date from this period, — probably the middle or later part of the Jurassic period.

The *Western Interior* or *Rocky Mountain* region had been mostly submerged during the Carboniferous age, as shown by the fact that limestones were forming there in the Coal-Measure period, and fossiliferous sandstones in the Permian. The Triassic sandstone there proves, by its nature, its gypsum in many places, and the paucity of fossils, that, by some change,

the region had become mostly an *interior* shallow salt sea, shut off to a great extent from the ocean. Such a sea would have been made too fresh for marine life in the rainy season, and probably too salt for almost all life in the hot season. Hence, life would have been nearly or quite absent. The salt waters by evaporation would have furnished gypsum to the beds, as happens now sometimes from sea-water. It follows, then, from the beds of the Atlantic border as well as those of the Western Interior, that the continent during the era of these Mesozoic beds was to a less extent submerged than in the greater part of the Paleozoic ages and the following portion of the Mesozoic. The fossiliferous Jurassic beds overlying the western Triassic show that, before the Jurassic period had closed, the sea had again free access over it and oceanic life was abundant.

2. **Foreign Geography.** — The nature of the Triassic beds of Britain and Europe shows that there were large *shallow interior seas* also on the eastern side of the Atlantic. The salt-deposits in the beds, the paucity of fossils in the most of the strata, and the prevalence of marlytes, indicate the same conditions as existed in New York during the formation of the Saliferous beds of the Upper Silurian (see page 100), and somewhat similar to those in which the Rocky Mountain Gypsiferous formation originated. The limestone that intervened along the Rhine, between the two formations of sandstone and marlytes, shows an interval of more open sea; yet the impurity of the limestone suggests that the ocean had not full sweep over the region.

The beds of the Jurassic period are almost all of them evidence, both from their constitution and their abundant marine life, that the free ocean again had sway over large portions of the Continental area. Its limits in Great Britain, however, became more contracted as the period passed, and toward its close fresh-water and terrestrial beds were forming in some places that had earlier in the period been under salt water.

3. **Climate.** — The Jurassic coral-reefs of Britain indicate that England then lay within the sub-tropical oceanic zone. This zone now has the parallel of 27° to 28° as, in general, its outer limit (lying mostly between 20° and 27°); and, consequently, its Jurassic limit, if including England, reached twice as far toward the pole as now. It is possible, however, that the line would have run along the British Channel, were it not for the Gulf Stream of the era, which carried the sub-tropical temperature northeastward through the British seas, as it now does to Bermuda, in latitude 34° .

The following are other facts of similar import. In Arctic America species of shells allied to those of Europe and tropical South America occur in latitudes 60° to $77^{\circ} 16'$; and one species of *Belemnite* and one of *Ammonite* are said to be *identical* with species occurring in these two remote and now widely different regions. If not absolutely identical, the evidence from them as to oceanic temperature is nearly the same. Moreover, on Exmouth Island, in $77^{\circ} 16' N.$, remains of an *Ichthyosaurus* have been found, and in $76^{\circ} 22' N.$, on Bathurst Island, bones of other large Jurassic Reptiles (*Teleosaurs*). It is probable, therefore, that a warm-temperate oceanic zone covered the Arctic to the parallel of 78° , if not beyond. No large living reptiles exist outside of the warm-temperate zone.

DISTURBANCES CLOSING THE JURASSIC PERIOD.

After the Jurassic period, or near its close, the lofty ranges of the Sierra Nevada, on the eastern boundary of California and the western of the Great Plateau or Basin were made; and probably also the Humboldt Range, above 12,000 feet in height, and other ranges over the dry plateau between the Sierra Nevada and the Wahsatch Range. Triassic and Jurassic fossils have been found in the rocks of the Sierra Nevada, while Cretaceous fossiliferous beds lie unconformably over the upturned strata of the mountains; the latter fact

proving that the mountain-making occurred before the Cretaceous era, and the former, that it took place after the Jurassic era. The ejections of trap in the Triassic-Jurassic areas of the Atlantic border occurred previous to the Cretaceous period, and perhaps contemporaneously with the making of the mountains on the Pacific border.

2. Cretaceous Period.

General characteristics. — The Cretaceous, while the closing period of Mesozoic time, was also, in some respects, a transition era between the Mesozoic and Cenozoic. During its progress, as is explained beyond, occurred the decline, and, at its close, the extinction, of a large number of the tribes of the mediæval world, while, at the same time, there appeared in its course other tribes eminently characteristic of the modern world. Among the modernizing features, the most prominent are the *Palms* and *Angiosperms* among plants, and the *Teliosts* among fishes.

The *Palms* and *Angiosperms* include nearly all the fruit-trees of the world, and constitute far the larger part of modern forests. The *Conifers* and *Cycads*, wherever they now occur near groves of *Angiosperms*, exhibit the contrast between the mediæval foliage and that of the present age. The *Teliosts* (page 176) embrace nearly all modern fishes excepting those of the order of *Sharks*, or *Selachians*. Their prevalence was as great a change for the waters as the new tribes of plants for the land.

1. Rocks: Kinds and Distribution.

In North America, the Cretaceous formation borders the continent on the Atlantic side, south of New York, and along the north and west sides of the Gulf of Mexico; besides, it spreads up the Mississippi Valley to the mouth of the Ohio; and, more to the westward, from Texas, northward, over the *slopes* of the Rocky Mountains, being now at a height in some

places of 10,000 to 12,000 feet above the sea. Its beds are exposed to view in New Jersey and in some portions of the more southern Atlantic States, though mostly covered by the Tertiary. They are largely displayed through Alabama and Mississippi, and cover a great area west of the Mississippi. (See map, page 195.) In the Rocky Mountain region they occur east of the Wahsatch, and south in Colorado, New Mexico, and beyond; also west of the Sierra Nevada in California of great thickness. In Colorado and New Mexico, and on Vancouver's Island, there are valuable beds of *brown coal* (sometimes called *lignite*) in the Cretaceous formation. The coal-beds of Wyoming and Utah, near the Central Pacific Railroad, and part of those to the south, are made Cretaceous by some geologists, and by others, Tertiary.

In England the formation occupies a region just east of the Jurassic, stretching from Dorset on the British Channel eastward, and also northeastward to Norfolk, on the German Ocean, and continuing near the borders of this ocean, still farther north, beyond Flamborough Head: it is numbered 9 on the map, page 244. Cretaceous rocks occur also in Northern and Southern France, and many other parts of Europe, covering much of the territory between Ireland and the Crimea, 1,140 miles in breadth, and, between the south of Sweden and south of Bordeaux, 840 miles.

Among the rocks there are the following kinds: the soft variety of limestone called *chalk*; hard limestones; ordinary hard sandstones; shales and conglomerates like those of other ages; but, more common than these, soft sand-beds, clay-beds, and shell-beds, so imperfectly consolidated that they may be turned up with a pick.

Many of the sand-beds or sandstones have a dark green color, and are called *green-sand*. The green color is owing to the presence of dark green grains which occur mixed with more or less of common sand. They are a hydrous silicate of iron and potash. This *green-sand* is often used for fertilizing land, and when so used it is called *marl*; it is extensively quarried for this purpose in New Jersey.

Chalk-beds are the source of *flint*. The flint is distributed through the chalk in layers, these layers being made up of nodules of flint, or masses of irregular forms. Although often of rounded forms, they are not water-worn stones of foreign origin, but were formed in place, like the *hornstone* in the Corniferous limestone of New York (page 229).

Chalk constitutes a large proportion of the Cretaceous formation in England and some parts of Europe. It occurs in the Cretaceous of Western Kansas, but not on the Atlantic border.

The succession of beds in England is as follows: 1. The *Lower Cretaceous*, consisting largely of the Green-sand and other arenaceous beds, called collectively the *Lower Green-sand*; 2. The *Middle Cretaceous*, containing the *Upper Green-sand* and some other beds; 3. The *Upper Cretaceous*, comprising the *Chalk-beds*, the lower part of which is without flints.

The Cretaceous beds in North America consist of layers of Green-sand, thick sand-beds of other kinds, clays, shell-beds, and, in some places in the States bordering on the Mexican Gulf (especially in Texas), limestone. The thickness of the formation in New Jersey is 400 to 500 feet; in Alabama, 2,000 feet; in Texas about 800, nearly all of it compact limestone; in the region of the Upper Missouri, 2,000 to 2,500 feet; east of the Wahsatch, 9,000 feet or more.

2. Life.

1. Plants.

The first of Angiosperms and of Palms, as already stated, date from the Cretaceous period. Leaves of a few American species of the former are represented in Figs. 370 – 373; Fig. 371, of a species of *Sassafras*; Fig. 372, a *Liriodendron*; and Fig. 373, a *Willow*; and with these occur leaves of *Oak*, *Dogwood*, *Beech*, *Poplar*, etc.

Besides these highest of plants, there were also Conifers, Ferns, and Sea-weeds, as in former time, with some Cycads. The microscopic Algæ called *Diatoms* (page 187), which make

siliceous shells, and others called *Desmids* (page 187), which consist of one or a few simple green cellules, were very abundant. Both occur fossil in flint; and a species of the latter

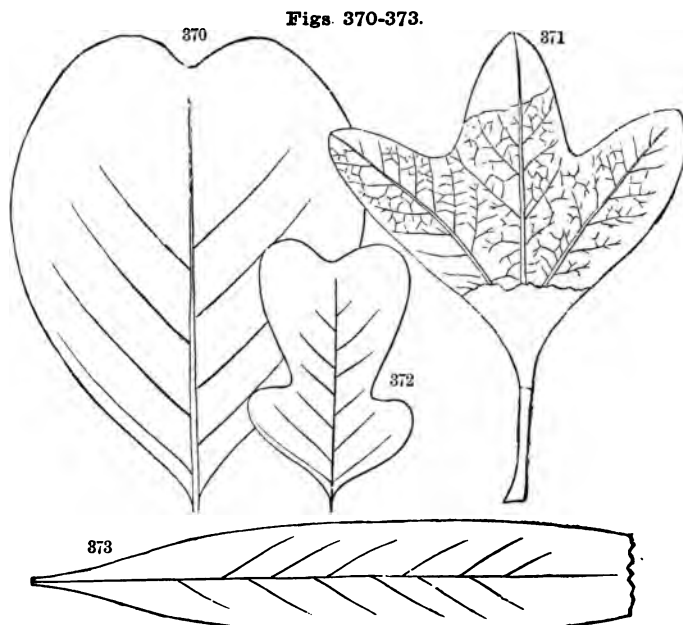


Fig. 370, *Leguminosites Marcouanus*; 371, *Sassafras Cretaceum*; 372, *Liriodendron Meekii*; 373, *Salix Meekii*.

is very similar to one from the Devonian hornstone figured on page 234 (Fig. 241). The Diatoms are believed to have contributed part of the silica of which the flint is formed.

2. Animals.

1. **Protozoans.** — The simplest of animals, *Rhizopods*, of the group of Protozoans (page 185), were of great geological importance in the Cretaceous period; for the Chalk is supposed to be made mostly of their minute calcareous shells. The powdered chalk is often found to contain large numbers of these shells, the great majority of which do not exceed a

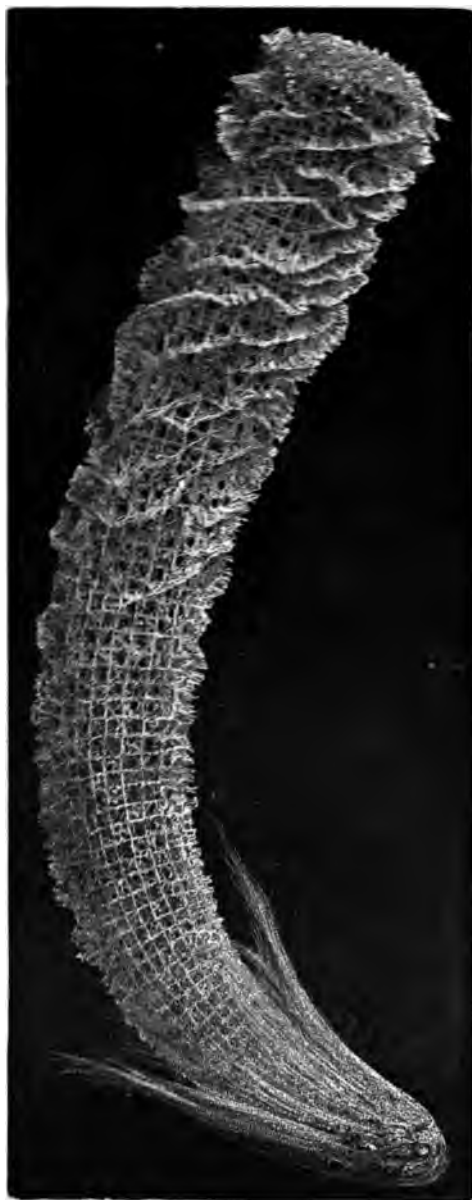
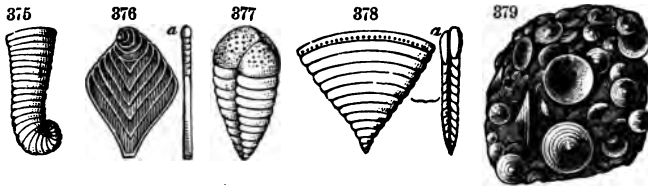


Fig. 374. — *Euplectella speciosa*, or Glass Sponge.

pin's head in size. A few of the forms are represented in Figs. 375 to 379, all very much enlarged, except 379, which is natural size. A very common kind resembles Fig. 83, (page

Figs. 375-379.



RHIZOPODS: Fig. 375, *Lituola nautiloidea*; 376, *Flabellina rugosa*; 377, *Chrysalidina gradata*; 378, *Cuneolina pavonia*; 379, *Orbitolina Texana*.

66), and is called a *Rotalia*. Fig. 379 represents a large disk-shaped species, called an *Orbitolina*, from Texas.

Besides the above Protozoans, Sponges were also very abundant, and their *siliceous spicules* (page 185) were another important source of the silica of the flints. Some of the Sponges, both of the Cretaceous era and of modern time in the deeper seas, consist wholly, or nearly so, of silica. One of the modern species, from deep water in the Indian Ocean, is represented in Fig. 374. It consists of a delicate network of fibres of silica, and looks as if made of spun glass. The *Ventriculites* were large Cretaceous sponges of similar character, having an inverted conical shape. Fig. 380 represents another kind which was probably siliceous.

Fig. 380.

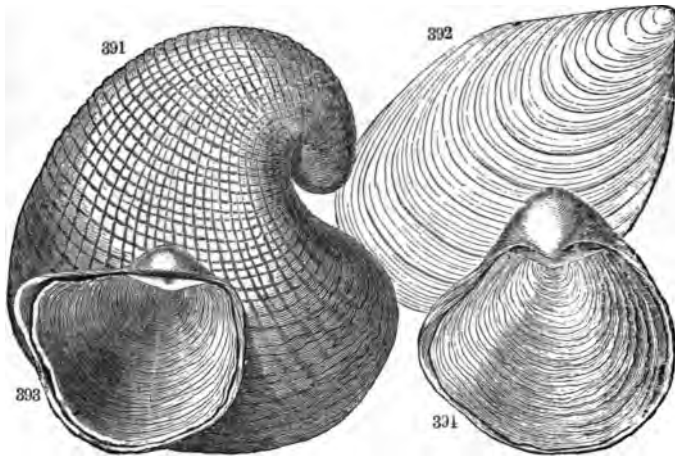


SPONGE. — *Siphonia lobata*.

2. **Radiates.** — **Mollusks.** — Corals and Echini were common among Radiates. Mollusks abounded, both of the Ammonite and Belemnite types, besides others of genera not peculiar to the Mesozoic. Many of the genera are represented in modern seas.

Figs. 391–393 are of some of the most characteristic Lamellibranchs from the American Cretaceous; Fig. 391, an *Exogyra*; Fig. 392, an *Inoceramus*; Figs. 393, 394, species of *Gryphæa*, — genera now extinct. Figs. 395, 396, represent shells of Gasteropods, and 397 to 401, Cephalopods, — all American except 399; Fig. 397, an upper front view of an *Ammonite*, showing the pockets along the sides of one of the partitions; Fig. 397 *a*, a reduced view of the same *Ammonite* in profile; Figs. 398 to 400, three species of the *Ammonite* family, but not true *Ammonites*, — one, Fig. 398, being called a *Scaphites* (from the Latin *scapha*, a *skiff*), resembling an

Figs. 391-394



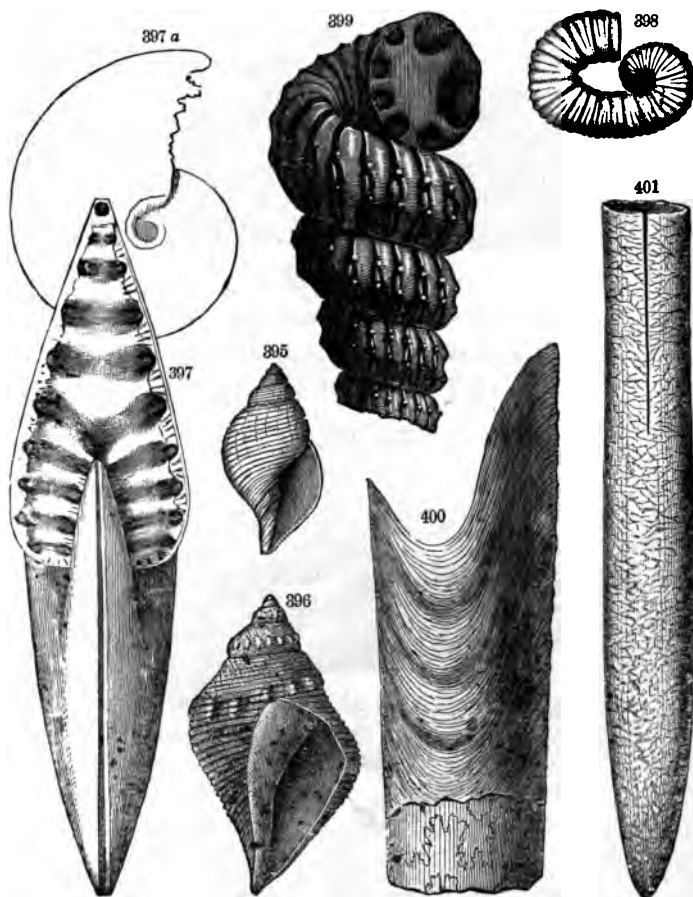
MOLLUSKS: Fig. 391, *Exogyra costata*; 392, *Inoceramus problematicus*; 393, *Gryphæa vesicularis*; 394, *G. Pitcheri*.

Ammonite with the shell partly uncoiled, and thus made somewhat to resemble a boat; Fig. 399, a *Turritites*, or *turreted Ammonite*, an anomaly in the family, as the species are almost all coiled in a plane; Fig. 400, a *Baculites*, or *straight Ammonite*, so named from the Latin *baculum*, a *walking-stick*. Some of the *Ammonites* of the Cretaceous period are 3 to 4 feet in diameter.

Fig. 401 represents a common New Jersey *Bellemnite*.

3. **Vertebrates.**— Among Vertebrates there were great numbers of the *Teliost* or *Osseous Fishes*,— fishes allied to the

Figs 395-401.



MOLLUSKS: Fig. 395, *Fasciolaria buccinoides*; 396, *Pyrifusus Newberryi*; 397, *Ammonites placenta*; 397 a, id., in profile, reduced; 398, *Scaphites larvæformis*; 399, *Turrillites catenatus*; 400, *Baculites ovatus*; 401, *Belemnitella mucronata*.

perch, salmon, pickerel, etc. They occur along with numer-

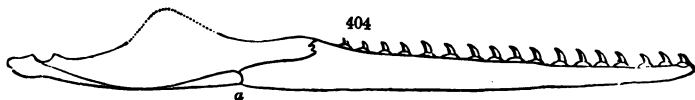
ous Sharks of both ancient and modern types (Cestracionts and Squalodonts), and many also of Ganoids. Thus the ancient and modern forms of fishes were united in the population of the Cretaceous seas, the former, however, making

Fig. 402.

Osmeroides Lewesiensis ($\times \frac{1}{2}$).

hardly more than a tenth of the species. Fig. 402 represents one of these Teliost Fishes, related to the *Salmon* and *Smelt*,

Figs. 403, 404.



MOSASAURS: Fig. 403, *Mosasaurus Hoffmanni* ($\times \frac{1}{15}$); 404, Side of jaw of *Edestosaurus dispar* ($\times \frac{1}{4}$).

from the Chalk at Lewes, England. There were also *Herring*, and many other kinds.

The Reptiles included species of several of the Jurassic genera. Of these, there were PTEROSAURS, of the genus *Pterodactylus*, and others, some, from Kansas rocks, 20 to 25 feet in expanse of wing; ENALIOSAURS, or Sea-Saurians, of the genera *Ichthyosaurus*, *Plesiosaurus*, etc., 10 to 50 feet long; and DINOSAURS, of the genera *Iguanodon*, *Hadrosaurus*, *Loelaps* (related to the Megalosaurus), etc., some of them fitted to raise themselves and walk on their hind feet, like the three-toed Reptiles of the Triassic-Jurassic era, in the Connecticut Valley (page 293).

There was also a tribe, unknown before the Cretaceous, that of the MOSASAURS: great snake-like Reptiles, 15 to 75 feet long, swimming by means of four paddles, —literally the Sea-Serpents of the era. The remains of the head of one, from the banks of the river Meuse in Holland (whence the name), are represented in Fig. 403. The American rocks have afforded forty species of these Mosasaurs. The head of the largest was four feet long, and the mouth was hence of enormous size. Besides, it had a joint in the lower jaw, either side, in place of the usual suture (at *a*, in Fig. 404), which enabled the two sides of a jaw, as the bones (rami) were not united at their extremities, to act like a pair of arms, in working down the immense throat any large animal it might undertake to swallow whole. A tooth of one of the Mosasaurs, half the natural size, is shown in Fig. 405.

Among more modern kinds of Reptiles there were Crocodiles and Turtles; one of the latter, from Kansas, 15 feet in breadth, according to Cope, between the tips of the extended flippers.

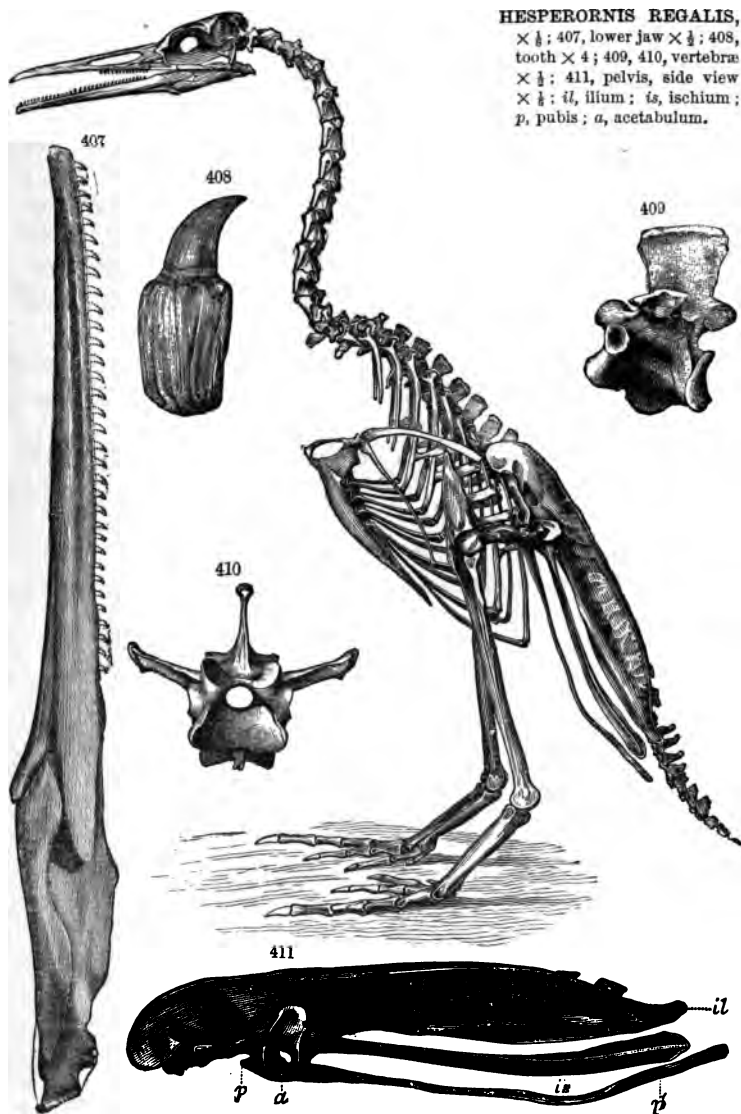
Fig. 405.



Tooth of *Mosasaurus princeps* ($\times \frac{1}{2}$).

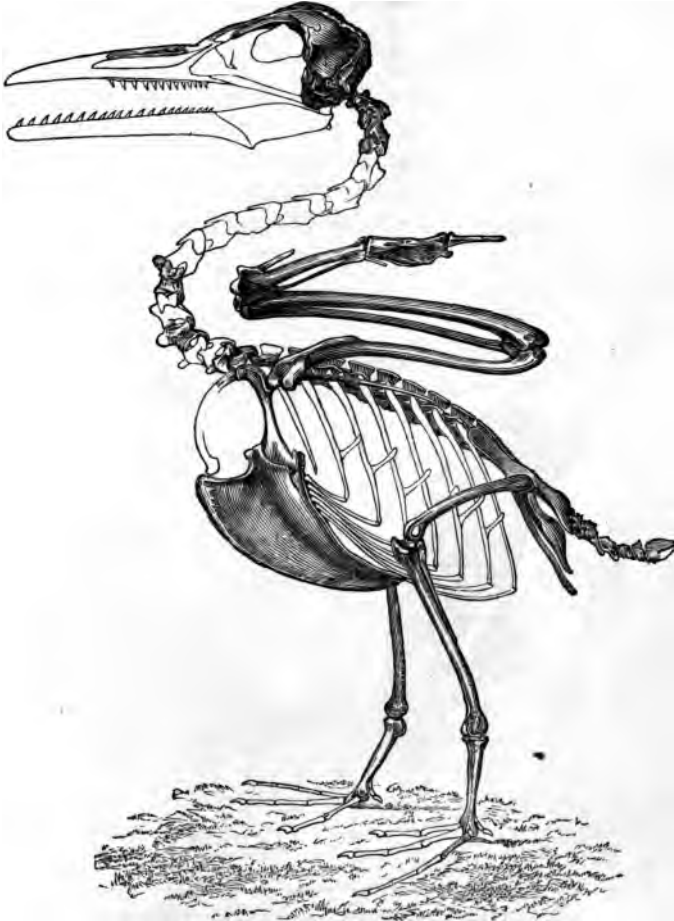
Fig. 406-411.

HESPERORNIS REGALIS,
 $\times \frac{1}{2}$: 407, lower jaw $\times \frac{1}{2}$; 408,
 tooth $\times 4$; 409, 410, vertebra
 $\times \frac{1}{2}$; 411, pelvis, side view
 $\times \frac{1}{2}$: *il*, ilium; *is*, ischium;
p, pubis; *a*, acetabulum.



The Birds in America included Divers, Cormorants, Waders. Some of them, as made known by Marsh, had teeth

Fig. 412.



Ichthyornis victor of Marsh.

like a Reptile. Fig. 406, from Marsh, represents the skeleton of *Hesperornis regalis*, one-eighth the natural size, a

gigantic Diver, 5 to 6 feet in height, between an Ostrich and a Loon in structure; and Fig. 412, *Ichthyornis victor*, half the natural size, a bird as large as a pigeon. The latter had *biconcave vertebræ*, like Fishes and Ichthyosaurs.

3. General Observations.

1. **Geography.**— In North America the position of the Cretaceous beds along the borders of the Atlantic south of New York, near the Mexican Gulf, and also over a large part of the Rocky Mountain region, indicates that these border regions and a large part of the Western Interior were under

Fig. 413.



North America in the Cretaceous Period; MO, Upper Missouri region.

water when the period opened, as represented in the above map (Fig. 413). The shaded part of the continent exhibits the extent to which it was submerged. (This map should be

compared with that on page 199.) It shows that the Chesapeake and Delaware gulfs were in the ocean; that Florida was still under water; that the region of the Missouri River was a salt-water region; that the Rocky Mountain region was largely submerged. This mountain region was in some parts at least 10,000 feet lower than now, the Cretaceous beds having this elevation upon it. The Mexican Gulf spread over a large part of Georgia, Alabama, and Mississippi, extended northward to the mouth of the Ohio, and then, west of Missouri and Kansas, stretched far north over the present slopes of the great Western mountains, reaching perhaps to the Arctic Ocean, though on this point the evidence is not yet decisive. The deposits, excepting those of Texas, appear to be of sea-shore and off-shore formations; the Texan compact limestones were probably formed in *clear* interior waters.

In Europe the Chalk appears to have been accumulated in an open sea, where the water was some hundreds of feet deep. The material of the Chalk has been stated on page 313 to be mainly the shells of Rhizopods, and that of the associated flint to have been derived largely from Diatoms and Sponges. Rhizopods, Diatoms, and Sponges are now living in many parts of the ocean, over the bottom, even where the depth is thousands of feet; and the Rhizopods are making chalk-like accumulations of vast area. There are, hence, in the present seas, the conditions requisite for making chalk, and also flint. The fossils of the Chalk are in many regions turned into flint, and some hollow specimens are filled with quartz crystals, or agate.

2. **Climate.** — The corals and other tropical life of the rocks indicate that the British seas were at least warm-temperate to latitude 60° north. On the American side the temperature of the waters appears to have been cooler, as it now is, in corresponding latitudes; and still it was considerably warmer than the present. The warm oceanic zone which spread over the British seas appears, from the distribution of the fossils, to have reached the North American coast south

of Long Island, and probably had no place on the coast north of Cape Hatteras. The plants of the Upper Missouri region indicate a warm-temperate climate over that territory.

GENERAL OBSERVATIONS ON THE MESOZOIC.

1. **Time-Ratios.** — The ratios between the Paleozoic ages as to the length of time that elapsed during their progress, or their *time-ratios*, are stated on page 269 as probably not far from 4 : 1 : 1. By the same method, it follows that the ratio for the time of the Paleozoic and Mesozoic was nearly 4 : 1; and for the Triassic, Jurassic, and Cretaceous periods, 1 : 1½ : 1. That is, Mesozoic time was about one fourth as long as the Paleozoic; and the three periods of the Mesozoic were not far from equal, the Jurassic being one quarter the longest.

2. **American Geography.** — On page 285 it is remarked that the Mesozoic formations were confined to the Atlantic and Gulf-border regions, and to an interior region west of the Mississippi covering much of the Rocky Mountain area, and that the intervening portion of the continent had probably become part of the dry land. The facts which have been presented in the preceding pages have sustained this statement. The Triassic-Jurassic beds, as has been shown, lie in long narrow strips between the Appalachians and the coast, and spread widely over the Rocky Mountain region and west nearly to the Pacific. The Cretaceous beds cover the Atlantic and Gulf borders, and also, like the Triassic, a very large part of the slopes of the Rocky Mountains and the Pacific border west of the Sierra Nevada. The eastern half of the continent during the Mesozoic was, therefore, receiving rock-formations only along its borders, while the western half had marine deposits in progress over its great interior and on the ocean's border.

The American Mesozoic deposits, for the most part, do not bear evidence that they were formed in a deep ocean. They appear to have accumulated mainly along coasts, or in shallow

waters off coasts, or in shallow inland seas ; the Cretaceous limestone of Texas indicates a pure sea, like that required for coral-reefs, but not necessarily one of great depth.

The Appalachians — the *eastern* mountains of the continent — had nearly their present elevation before the early Mesozoic beds commenced to form (page 283). But the region of the Rocky Mountains — the *western* chain — was to a great extent still a shallow sea even during the Cretaceous period, or when the Mesozoic era was drawing to its close (page 320).

Only one series of mountain-elevations can be pointed out, with our present knowledge, as originating in Eastern North America in the course of the Mesozoic era, although great oscillations of level were much of the time in progress. This one is that of the Mesozoic red sandstone and trap along the Atlantic border region, as explained on page 307.

On the western side of the continent the mountain-making after the Jurassic was on a far grander scale, the Sierra Nevada and other high ranges dating from this epoch.

3. European Geography. — Europe has its Mesozoic rocks distributed in patches, or in several independent or nearly independent areas, which show that it retained its condition of an archipelago throughout Mesozoic time. The oscillations of level, as indicated by the variations in the rocks, — variations both as to the nature of the beds and their distribution, — were more numerous and irregular than in North America. The mountain-elevations formed, however, were few and small compared with those that followed either the Paleozoic or the Mesozoic era. One series of disturbances is referred to the close of the Triassic, and another to that of the Jurassic.

Among the Mesozoic formations of the European continent there are deposits of all kinds, — those of sea-shores ; of off-shore shallow waters ; of inland seas ; of moderately deep oceanic waters ; and of marshy, or dry and forest-covered land.

Both in America and Europe there were some coal-beds made, though of small extent compared with those of the Carboniferous age.

4. **Life.** — The Mesozoic era witnessed — (1) the decline of some ancient or Paleozoic types of both plants and animals, (2) the increase and culmination of mediæval or Mesozoic types, and (3) the beginning of some of the most important of modern or Cenozoic types.

1. *Disappearance of Ancient or Paleozoic features.* — Among the ancient tribes of plants, the *Calamites*, or Tree-rushes, and several genera of Ferns, disappear in the Jurassic. Among the old Brachiopod tribes, the *Spirifer* and *Leptaena* families end in the Triassic; among higher Mollusks, the Silurian type of *Orthoceras*, and Devonian of *Goniatites*, have their last species in the Triassic; in Fishes, the Ganoids lose the vertebrated feature of their tails, characterizing them in the Paleozoic, in the same period, and thus bear evidence of progress.

2. *Progress in Mesozoic features.* — The *Cycads*, among plants, were those most characteristic of the Mesozoic: they afterward yielded to other kinds, and now are nearly an extinct tribe. The *Cephalopods*, among Mollusks, existed in vast numbers, both those with external shells, as the *Ammonites*, and those without, as the *Belemnites*. The whole number of species of Cephalopods now known from the Mesozoic formations is nearly 1,200. Of these, about 950 were of the *Nautilus* and *Ammonite* families. No *Ammonite* now exists, and the only chambered species which are now living are 2 or 3 of the genus *Nautilus*. The whole number of species of Cephalopods living in the course of the Mesozoic era may have been three or four times 1,200, since only a part would have been preserved as fossils. The sub-kingdom of Mollusks, therefore, culminated in the Mesozoic era; for its highest order, that of the Cephalopods, was then at its maximum.

The type of Reptiles was another that expanded and reached its height, — that is, its maximum in number, variety, and rank of species, — and commenced its decline in the Mesozoic era.

There were huge swimming Saurians, Enaliosaurs, in the place of whales in the sea; bat-like Saurians or Pterodactyls

flying through the air; four-footed Saurians, both grazing and carnivorous, many of them 25 to 50 feet long, occupying the marshes and estuaries; great biped Saurians or Dinosaurs over the land; and snake-like Mosasaurs in the ocean, some having the great length of 75 or 80 feet.

In the era of the Wealden and Lower Cretaceous there lived, in and about Great Britain, 4 or 5 species of Dinosaurs 20 to 50 feet long, 10 to 12 Crocodilians, Lizards, and Enaliosaurs 10 to 50 feet long, besides Pterodactyls and Turtles; and many more than this, since all that lived would not have left their remains in the deposits. To appreciate this peculiarity of mediæval time, it should be considered that in the present age Britain has no large Reptiles; in Asia there are only *two* species over 15 feet in length; in Africa but *one*; in all America but *three*; in the whole world not more than *six*; and the largest of the six does not exceed 25 feet in length. North America, during the Cretaceous, appears to have exceeded all the world beside in the number and size of its Reptiles. The Mesozoic era is well named the *Age of Reptiles*.

All the Mesozoic animals, excepting the Mammals, belong to the *oviparous* divisions; and the Mammals were mainly Marsupial species, — that is, *semi-oviparous* Mammals, as explained on page 176, — species quite in harmony, therefore, with the other life of the era. The Birds of the age, or at least some of them, partook of the Reptilian features of the time, having long tails like the associated Reptiles (though feathered tails), with other peculiarities of the scaly tribes; and some even had reptile-like teeth. The long-tailed birds and Pterodactyls were the flying creatures of the age; the Ichthyosaurs and Plesiosaurs, and the like, the “great whales”; the Teleosaurs, Iguanodon, and other gigantic species of the estuaries and marshes, the creeping species. These, along with the small Marsupials of the Cycadean and Coniferous forests, were the more prominent kinds of Mesozoic life.

3. Introduction of Cenozoic features. — Among plants the first of *Angiosperms* (or the order including all trees having

a bark excepting the Conifers, as the Oak, Maple, Apple, etc.), and the first of *Palms* are found in the Cretaceous. These become the characteristic plants of Cenozoic time.

Among *Vertebrates* there was a great expansion, if not the first, of the great order of Teliost or Osseous Fishes, the species characteristic of earlier time having been either Selachians (Shark tribe), Ganoids, or Placoderms (page 237). The first of the modern genus of *Crocodylus* occurs in the Jurassic; the first of Birds in the Triassic or Jurassic, — the Reptilian Birds; the first of Mammals in the Triassic, — Marsupials, or semi-oviparous Mammals.

Of the classes of Vertebrates, Fishes and Reptiles commence in the middle and later Paleozoic, and Birds and Mammals in the early or middle Mesozoic.

Extinction of life at the close of the Cretaceous. — At the close of the last period of the Mesozoic era — the Cretaceous — there was an extermination of species over a large part of the Continental seas as complete as that closing the Paleozoic era. In Europe, Asia, and Eastern North America no Cretaceous species have been found fossil in any Tertiary strata. In the Rocky Mountain region and the Pacific border it is probable that some Cretaceous species continued on into the Tertiary, as stated beyond (page 337). There is no reason for asserting that the species of the open ocean were exterminated; on the contrary, it is believed that at least one Cretaceous Mollusk — a *Terebratula* — still exists in the depths of the Atlantic.

Besides the destruction of species, there was the final extinction of several families and tribes. The great family of Ammonites, and many others of Mollusks, all the genera of Reptiles excepting *Crocodylus*, and others in all departments of life, came to their end at the close of the Cretaceous or soon after.

Extinction over so wide a range of Continental seas must have been due to a cause which acted as widely, and no other appears to be sufficient excepting a change of climate

in the north. The Arctic and other high-latitude regions may have been elevated more than those of lower latitudes, for Tertiary rocks do not occur on the eastern borders of the American continent north of the parallel of 42° N. to show that the continent was then below its present level. Connected with the elevation of the land to the north there may have been an exclusion of warm oceanic currents from the Arctic seas; for in Behring Straits the depth of water is less than 200 feet. By these means a semi-glacial epoch may have been occasioned which sent cold oceanic currents from the north along the sea-borders and Continental seas to the south. Should the cold winds and cold oceanic currents of the northern part of the existing temperate zone penetrate for a single year into the tropical regions, they would produce a general extermination of the plants and animals of the land, and also of those of the coast and sea-borders, as far as the cold oceanic currents extended. A change to a climate no colder than the present would have been sufficient probably for all the destruction that took place, since the life of the Cretaceous seas, even in Northern Europe, was largely that of the warm-temperate zone.

While the emergence of northern lands here appealed to may have taken place as the Cretaceous period closed, there appears to have been no mountain-making of much extent until the Tertiary age had already far advanced (page 346).

IV. — CENOZOIC TIME.

1. CENOZOIC TIME covers two ages: 1. THE TERTIARY AGE, or AGE OF MAMMALS; and 2. THE QUATERNARY, or AGE OF MAN.

2. **General characteristics.**—In the transition to this era the life of the world takes on a new aspect. Trees of modern types — Oak, Maple, Beech, etc., and Palms — unite with

Conifers to make the forests; Mammals of great variety and size, — Herbivores, Carnivores, and others, successors to the small semi-oviparous Mammals, tenant the land in place of Reptiles; Birds and Bats possess the air in place of reptilian Birds and Pterodactyls; Whales and Teliost or common Fishes, with Sharks, mainly of modern type, occupy the waters in place of Enaliosaurs, and almost to the exclusion of the ancient tribes of Cestracient Sharks and Ganoids. Finally Man appears when Mammals were passing their maximum in grade and magnitude, and becomes the dominant species of the finished world.

I. TERTIARY AGE, or AGE OF MAMMALS.

The Mammals of this age are all extinct species, and the other species of life largely so; the number of living species of Invertebrates (Radiates, Mollusks, and Articulates) varies from perhaps one per cent in the early part of the age to 90 in the latter. In the Quaternary the Mammals of the earlier part are nearly all of extinct species; the Invertebrates are almost wholly of living species.

I. Periods.

The Tertiary strata have been divided by Lyell into three groups:

1. **Eocene** (from the Greek *ἥως*, *dawn*, and *καινός*, *recent*): species nearly all extinct.

2. **Miocene** (from *μείων*, *less*, and *καινός*): less than half the species living.

3. **Pliocene** (from *πλείων*, *more*, and *καινός*): more than half the species living.

These subdivisions are not necessarily those marked off by the grander physical changes of a continent.

In North America there was:—

1. The **Lignitic** period, corresponding to the Lower Eocene, or else intermediate between the Tertiary and Cretaceous.

The beds follow on conformably after the Cretaceous; and then, as the period closed, these Lignitic strata, along with the underlying Cretaceous, which were also largely lignitic, were together upturned, lifted into mountains, and partly rendered metamorphic; and this happened both in the Rocky Mountain region and in California. This mountain-making epoch makes a natural ending of the period.

2. The **Alabama** period, corresponding to the remainder of the Eocene. The beds in the Rocky Mountain region overlie nearly or quite horizontally the upturned Lignitic and Cretaceous beds. On the Gulf of Mexico they include the marine beds of Claiborne, Alabama, and of Jackson and Vicksburg, Mississippi. The close of the period was marked off by a change over the lower part of the Mississippi Valley about the Gulf; for no marine Tertiary strata later than Eocene exist in those regions. The country in the line of Florida to the northwest, now 300 to 700 feet above the sea-level, is the western boundary of the area of the later Tertiary.

3. **Yorktown**, or that of the beds of Yorktown, Virginia, in which 20 to 40 per cent of the species are living, — usually called *Miocene*, but possibly including part, at least, of the Pliocene.

A fourth has been separated as *Pliocene*, or the **Sumter** epoch, based on observations on the beds in Sumter and Darlington districts, South Carolina; but according to Conrad, it may not be distinct from the Yorktown.

2. Rocks: Kinds and Distribution.

The beds are either of *marine* or of *fresh-water* origin.

The *marine* Tertiary beds of North America border the continent south of New England along both the Atlantic Ocean and the Mexican Gulf, overlying the Cretaceous in part. The most northern locality is on Martha's Vineyard. (See map, page 195, in which the area is lined obliquely from the left above to the right below.) They spread northward

to the mouth of the Ohio, and also westward into Texas, west of the Mexican Gulf.

The *marine* Tertiary beds do not, like the Cretaceous, stretch north and northwest up the eastern slopes of the Rocky Mountains; but, instead, there are over these slopes extensive *fresh-water* Tertiary strata (formed in and about great lakes), with in many places some of the lowest beds of brackish-water origin, as shown by the fossils. This fresh-water Tertiary extends over the summit region of the Rocky Mountains; and there the lower part includes not only brackish-water, but also salt-water, beds, along with those of fresh-water formation. *Marine* Tertiary occurs also in California and Oregon, not far from the coast.

The *Lignitic* period, or early Eocene, includes brackish-water, and associated fresh-water, strata in the Upper Missouri and Rocky Mountain regions. They are remarkable for containing extensive beds of good mineral coal, called *brown coal* or *lignite*, whence the name of the period. These coal-beds are worked at Evanston, Coalville, and other places on or near the Central Pacific Railroad. In Colorado and New Mexico the Lignitic Tertiary passes downward, according to the statements of some observers, into lignitic strata that belong to the Upper Cretaceous.

Lignitic beds underlying the *marine* Tertiary of the Mississippi Valley south of the Ohio are also of this era.

The *Alabama* period, or the *Middle* and *Later Eocene*, comprises the marine Tertiary of the Gulf border from Mississippi eastward, and the lower beds of the Tertiary formation along the Atlantic border.

To the *Yorktown* period, or *Miocene*, belong the marine Tertiary beds of the Atlantic border from New Jersey to South Carolina, overlying the Eocene; and fresh-water strata of great extent in the Upper Missouri region and elsewhere over the eastern slopes of the Rocky Mountains.

The *Pliocene* Tertiary, besides including possibly marine beds in South Carolina, as mentioned above, comprises fresh-

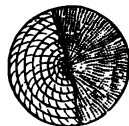
water beds in the Upper Missouri region, and to the south, where they overlie the Miocene fresh-water strata, and, like them, are of lacustrine origin.

The Tertiary rocks are generally but little consolidated; they consist mostly of compacted sand, pebbles, clay, earth that was once the mud of the sea-bottom or of estuaries, mixed often with shells, or are such kinds of deposits as now form along sea-shores and in shallow bays and estuaries, or in shallow waters off a coast. There are also limestones made of shells, and others of corals, resembling the reef-rock of coral seas. The latter are found mainly in the States bordering on the Mexican Gulf. Another variety of rock is *buhrstone*, a cellular siliceous rock, flinty in texture, used, on account of its being so hard and at the same time full of irregular cavities, for making millstones. It is found in South Carolina and Alabama.

The Tertiary of Great Britain occurs mostly in the southeastern part of England, in the London basin as it is called, and on the southern and eastern borders of the island, adjoining the Cretaceous.

On the continent of Europe the Paris basin is noted for its Eocene strata and fossil Mammals. Other Tertiary areas are those of the Pyrenean and Mediterranean regions, those of Switzerland; of Austria, etc. Some of the marine Eocene beds contain Rhizopods (p. 185) having the shape of a coin, called Nummulite (from the Latin *nummus*, a coin). One is here figured, of natural size; it has the exterior of half of it removed to show the cells within. Occasionally the beds are so far made up of these Nummulites that the rock is called *Nummulitic limestone*.

Fig. 414.



Nummulite.

These marine Eocene strata spread very widely over Europe, Northern Africa, and Asia,—occurring in the Pyrenees, forming some of their summits; in the Alps to a height of 10,000 feet; in the Carpathians, in Algeria, in Egypt, where the most noted pyramids are made of Nummulitic limestone,

in Persia, in the Western Himalayas (the region of Cashmere), to a height of 16,500 feet. The later Tertiary formations are much more limited in distribution, and many are of terrestrial or fresh-water origin.

The rocks are similar to those of North America, but include more of hard sandstone and limestone. The sandstone is a very common building-stone in different parts of Europe, being soft enough to be worked with facility, yet generally hardening on exposure, owing to the fact that it contains calcareous particles (trituated shells), which render the percolating waters or rain calcareous, so that on evaporating they produce a calcareous deposit, as a cement, among the grains of sand.

The Eocene formation of Southeastern England consists of beds of clay and sand, the lowest of sand sometimes containing rolled flints. The *Lower Eocene* includes the Thanet sands, Woolwich beds, and London clay; the *Middle Eocene*, the lower Bagshot beds; the *Upper Eocene*, the Barton clay, Bembridge beds, and the Hempstead beds near Yarmouth. The *Older Pliocene* includes the Coralline crag and Red crag of Suffolk; and the *Newer Pliocene*, the Norwich crag, which is of fluvio-marine origin. No marine Miocene beds have yet been identified in Great Britain.

1. Life.

1. Plants.

The great feature of the Tertiary vegetation is the prevalence of Angiosperms, the tribe of plants which, thus far, is unknown before the Cretaceous. Leaves of *Oak*, *Poplar*, *Maple*, *Hickory*, *Dogwood*, *Mulberry*, *Magnolia*, *Cinnamon*, *Fig*, *Sycamore*, *Willow*, and many others, have already been found in both American and European Tertiary strata, besides the remains of Palms and Conifers. A leaf of a Tertiary Fan-palm (species of *Sabal*), found in the Upper Missouri, must have been, when entire, 12 feet in breadth. Nuts are also common in some beds, — as at Brandon, Vermont. Fig. 415 is the

leaf of an Oak ; Fig. 416, of a species of Cinnamon ; Fig. 417, of a Palm ; Fig. 418, the nut of a beech, closely like that of

Figs. 415-419.

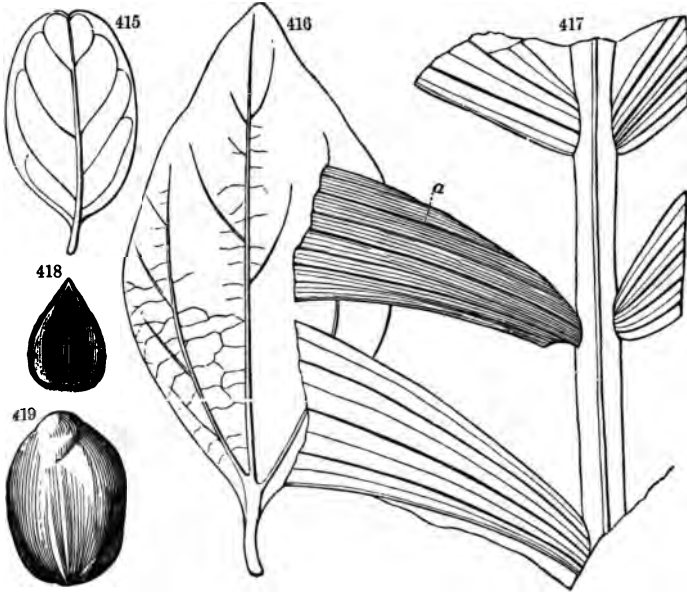


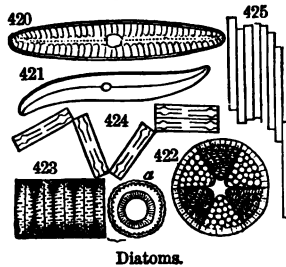
Fig. 415, *Quercus myrtifolia* ? ; 416, *Cinnamomum Mississippense* ; 417, *Calamopsis Danæ* ; 418, *Fagus ferruginea* ? ; 419, *Carpolithes irregularis*.

the common beech ; Fig. 419, another nut, from Brandon, of unknown relations.

The Eocene Plants of Great Britain included Palms, and among those of Central and Southern Europe there were many species related to the trees of Australia ; while the Miocene and Pliocene had much similarity to those of America.

The microscopic plants which form siliceous shells, called Diatoms (Figs. 420 to 425, all

Figs. 420-425.

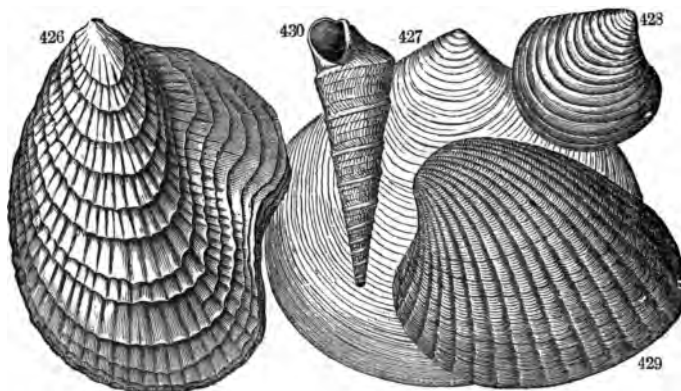


greatly enlarged), make extensive deposits in some places. One stratum near Richmond, Virginia, is 30 feet thick, and is many miles in extent; another, near Monterey, California, is 50 feet thick, and the material is as white and fine as chalk, which it resembles; another, near Bilin in Bohemia, is 14 feet thick. The material from the latter place was used as a polishing-powder (and called Tripoli, or polishing-slate) long before it was known that its fine grit was owing to the remains of microscopic life. Ehrenberg has calculated that a cubic inch of the fine earthy slate contains about forty-one thousand millions of organisms. Such accumulations of Diatoms are made both in fresh waters and salt, and those of the ocean at all depths.

2. Animals.

The most prominent fact with regard to the Tertiary Invertebrates is their general resemblance to modern species. Although a number of the genera are extinct, and nearly every Eocene species, there is still a modern look in the re-

Figs. 426-430.

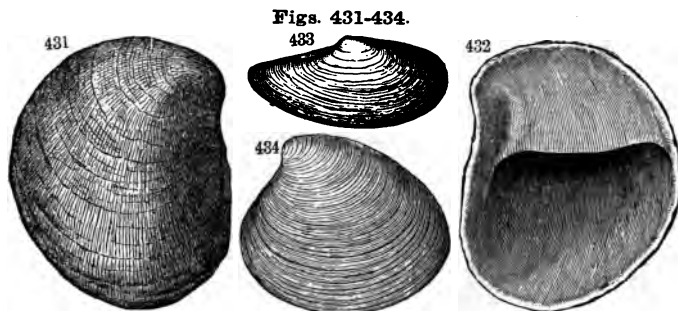


LAMELLIBRANCHS: Fig. 426, *Ostrea sellaeformis*; 427, *Crassatella alta*; 428, *Astarte Conradi*; 429, *Cardita planicosta*. — GASTEROPOD: 430, *Turritella carinata*.

mains, and the specimens have often the freshness of a shell from a modern beach.

The preceding are figures of a few Mollusks of the marine Eocene, from Claiborne, Alabama. Fig. 426 represents an Eocene *Ostrea*; Fig. 427, a species of *Crassatella*; Fig. 428, an *Astarte*; Fig. 429, a *Cardita*; and Fig. 430, a *Turritella*.

Figs. 431 to 434 are species of Miocene shells, from Virginia; Figs. 431, 432, represent a very common *Crepidula*.



GASTEROPOD : Figs. 431, 432, *Crepidula costata*. — LAMELLIBRANCHS : Fig. 433, *Yoldia limatula*; 434, *Callista Sayana*.

upper and under sides. The species of the epoch include the common *Oyster* and *Clam*, and other modern species; and these are, therefore, among the most ancient of living species on the globe. The Lignitic beds of the Rocky Mountain region in Wyoming Territory and elsewhere contain a very few Cretaceous species, among them the *Inoceramus problematicus*.

With regard to Vertebrates the points of special interest are the following:—

1. In the class of Fishes: (1) The prevalence of *Teliosts*, or fishes allied to the Perch and Salmon, as already stated; and (2) the abundance of Sharks, some of them having teeth 6 inches long and broad. The teeth of sharks are the durable part of the skeleton; they are very abundant in both Eocene and Miocene beds. Fig. 436 represents a tooth of the *Carcharodon angustidens*. The larger teeth above alluded to belong to the *Carcharodon megalodon*, and are found at different places on the Atlantic border from Martha's Vineyard southward.

Fig. 435 represents the tooth of another common kind of Shark, a species of *Lamna*, from Claiborne.

In the class of Reptiles: The existence of numerous *Crocodyles* and *Turtles*. The shell of one of the Miocene turtles, found fossil in India, had a length of 12 feet, and the animal is supposed to have been 20 feet long. The first of true *Snakes*, moreover, occur in the Eocene.

Dinosaurian remains, unknown in Europe above the Cretaceous, occur sparingly in the Lignitic beds of the Rocky Mountain region, and have strengthened the doubt whether these beds are not part of the Upper Cretaceous.

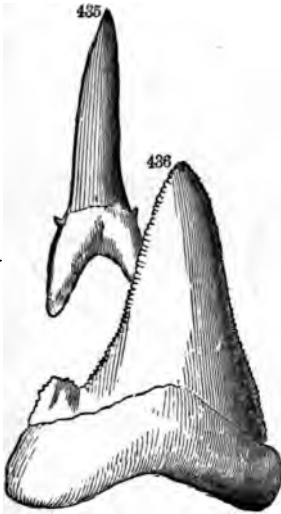
In the class of Birds: The species found are not long-tailed, or in any respect reptilian, but resemble modern birds; they are related to the *Pelican*, *Waders*, *Pheasants*, *Perchers*, *Vultures*, *Owls*, *Woodpeckers*, and other kinds.

In the class of Mammals: The occurrence of the first of *Whales*, the first of *Carnivores*, *Herbivores*, *Rodents*, *Monkeys*, and of other tribes, indicating a large population of brute animals, different from the present in species, though, in general, related to the modern kinds in form and structure. A few, however, are widely diverse from anything in existence, — such combinations as the mind would never have imagined without aid from the skeletons furnished by the strata.

In the early Eocene there appear to have been more *Herbivores* than *Carnivores*; but afterward the *Carnivores* were as common as now.

Cuvier first made known to science the existence of fossil

Figs. 435, 436.



TEETH OF SHARKS. — Fig. 436, *Carcharodon angustidens*; 435, *Lamna elegans*.

Tertiary Mammals. The remains from the earthy beds about Paris had been long known, and were thought to be those of modern beasts. But, through careful study and comparisons with living animals, he was enabled to bring the scattered bones together into skeletons, ascertain the tribe to which they belonged, and determine the food and mode of life of the ancient but now extinct species. Cuvier acquired his skill by observing the mutual dependence which subsists between all parts of a skeleton, and, in fact, all parts of an animal. A sharp claw is evidence that the animal has trenchant or cutting molar teeth, and is a flesh-eater; a hoof, that he has broad molars and is a grazing species; and, further, every bone has some modification showing the group of species to which it belongs, and may thus be an indication, in the hands of one well versed in the subject, of the special type of the animal, and of its structure, even to its stomach within and its hide without.

One of these Paris beasts from the middle Eocene beds is called a *Paleothere*, from the Greek *παλαιός*, *ancient*, and *θήριον*, *wild beast*. It is related to the modern Tapirs (Fig.

Fig. 437.



Tapirus Indicus.

437), and was of the size of a horse. Another kind, called a *Xiphodon*, was of more slender habit, and somewhat resembled

Fig. 435 represents the tooth of another common kind of Shark, a species of *Lamna*, from Claiborne.

In the class of Reptiles: The existence of numerous *Crocodyles* and *Turtles*. The shell of one of the Miocene turtles, found fossil in India, had a length of 12 feet, and the animal is supposed to have been 20 feet long. The first of true *Snakes*, moreover, occur in the Eocene.

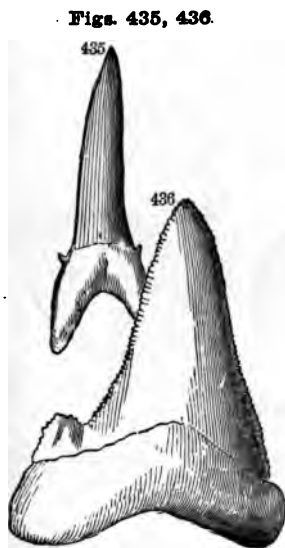
Dinosaurian remains, unknown in Europe above the Cretaceous, occur sparingly in the Lignitic beds of the Rocky Mountain region, and have strengthened the doubt whether these beds are not part of the Upper Cretaceous.

In the class of Birds: The species found are not long-tailed, or in any respect reptilian, but resemble modern birds; they are related to the *Pelican*, *Waders*, *Pheasants*, *Perchers*, *Vultures*, *Owls*, *Woodpeckers*, and other kinds.

In the class of Mammals: The occurrence of the first of *Whales*, the first of *Carnivores*, *Herbivores*, *Rodents*, *Monkeys*, and of other tribes, indicating a large population of brute animals, different from the present in species, though, in general, related to the modern kinds in form and structure. A few, however, are widely diverse from anything in existence,—such combinations as the mind would never have imagined without aid from the skeletons furnished by the strata.

In the early Eocene there appear to have been more *Herbivores* than *Carnivores*; but afterward the *Carnivores* were as common as now.

Cuvier first made known to science the existence of fossil

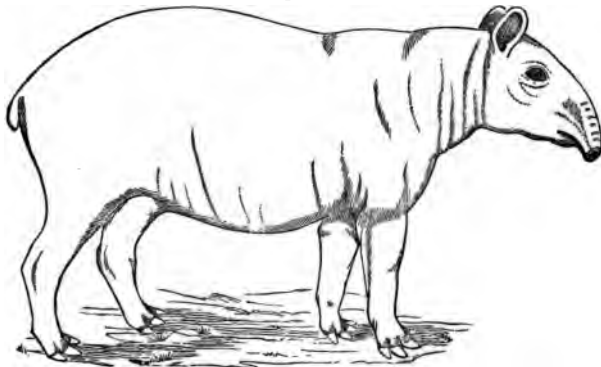


TEETH OF SHARKS. — Fig. 436, *Carcharodon angustidens*; 435, *Lamna elegans*.

Tertiary Mammals. The remains from the earthy beds about Paris had been long known, and were thought to be those of modern beasts. But, through careful study and comparisons with living animals, he was enabled to bring the scattered bones together into skeletons, ascertain the tribe to which they belonged, and determine the food and mode of life of the ancient but now extinct species. Cuvier acquired his skill by observing the mutual dependence which subsists between all parts of a skeleton, and, in fact, all parts of an animal. A sharp claw is evidence that the animal has trenchant or cutting molar teeth, and is a flesh-eater; a hoof, that he has broad molars and is a grazing species; and, further, every bone has some modification showing the group of species to which it belongs, and may thus be an indication, in the hands of one well versed in the subject, of the special type of the animal, and of its structure, even to its stomach within and its hide without.

One of these Paris beasts from the middle Eocene beds is called a *Paleotherium*, from the Greek *παλαιός*, *ancient*, and *θήριον*, *wild beast*. It is related to the modern Tapirs (Fig.

Fig. 437.



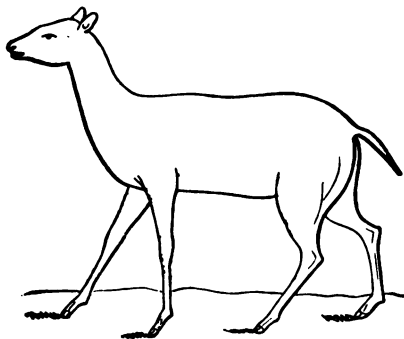
Tapirus Indicus.

437), and was of the size of a horse. Another kind, called a *Xiphodon*, was of more slender habit, and somewhat resembled

a stag, as shown in Fig. 438. There were others, related to the hog, or Mexican Peccary; also some Carnivores, a Bat, and an Opossum.

Among American *Eocene* Mammals there is a species of whale of great length, called a *Zeuglodon*, from *ζεύγλη*, *yoke*, and *ὀδούς*, *tooth*, in allusion to the fact that part of the teeth have two long prongs which give them a yoke-like shape.

Fig. 438



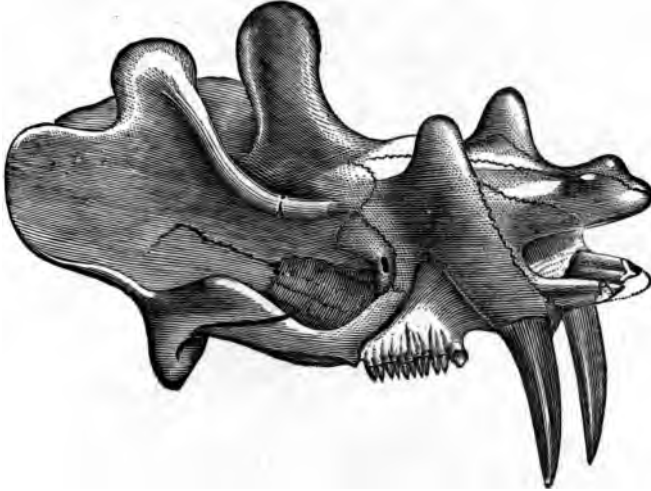
Xiphodon gracile.

The bones occur in many places in the Gulf States, and in Alabama the vertebræ were formerly so abundant as to have been built up into stone walls, or burned to rid the fields of them. The living animal was probably 70 feet in length. One of the larger vertebræ measures a foot and a half in length and a foot in diameter.

The Lignitic beds, or early Eocene of North America, have afforded no Mammalian remains. But, from the overlying Middle or Later Eocene, of the Green River basin, near Fort Bridger, a large number of species have been obtained. The skull of one kind, of elephantine size, having six horn-cores, and called by Marsh *Dinoceras*, in allusion to its horns, is represented in Fig. 341. It was somewhat related to the Rhinoceros. There were also the earliest of the Horse tribe, called *Orohippus*; and it is remarkable that these Eocene Horses had four usable toes (Fig. 440) instead of the one only of the

modern Horse. The relations in the foot of the latter to different kinds of Tertiary Horses are illustrated in Figs. 440-443.

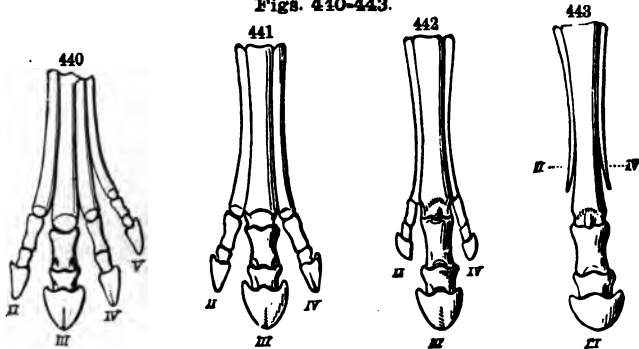
Fig. 439.



Dinoceras mirabile ($\times \frac{1}{4}$).

In Fig. 443 it is shown that the *modern Horse* has one usable toe, the third, and rudiments of two others, the second

Figs. 440-443.



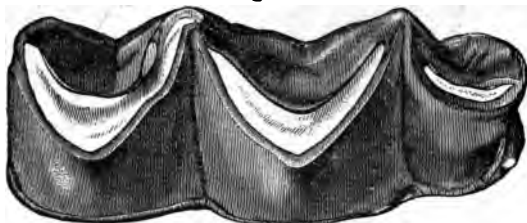
FEET OF SPECIES OF THE HORSE TRIBE. — Fig. 440, *Orohippus*, of the Eocene ($\times \frac{2}{3}$); 441, *Anchitherium*, of the Miocene; 442, *Hipparion*, of the Pliocene; 443, the modern Horse.

and fourth, in what are called the splint-bones. In the *Hipparion*, of the Pliocene (Fig. 442), the second and fourth have hoofs, but they are not usable. In *Anchitherium*, of the Miocene (Fig. 441), the second and fourth toes come to the ground, and are therefore usable. In *Orohippus* (Fig. 440), not larger than a small-sized dog, there are four toes, and all are usable.

Other Wyoming species are related to the Tapir and Hog, some approaching in characters the Paris *Paleothere*. There were also Monkeys, some Carnivores related to the Cat and Wolf, Bats, Squirrels, Moles, and Marsupials.

The *Miocene* beds of the "Bad Lands" on the White River, in the Upper Missouri region and elsewhere in the West, have afforded remains of other Mammals. Among them are several

Fig. 444.

Tooth of *Titanotherium proutii* ($\times \frac{1}{2}$).

Carnivores related somewhat to the *Hyena*, *Dog*, and *Panther*; many Herbivores, including *Rhinoceroses*, species approaching the *Tapir*, *Peccary*, *Deer*, *Camel*, *Horse*; Rodents. Fig. 444

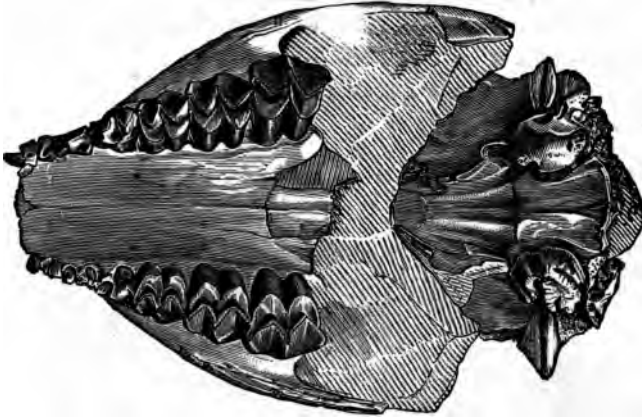
Fig. 445.

Teeth of *Rhinoceros (Hyracodon) nebrascensis*.

represents a tooth, half the natural size, of a *Titanotherium*, an animal related to the Tapir and *Paleothere*, but of elephantine size, standing probably 7 or 8 feet high. Fig. 445 repre-

sents a few of the teeth of an animal related to the Rhinoceroses. Another species, the *Brontotherium*, nearly as large as an Elephant, but related somewhat to the Rhinoceros, had a pair of great horns.

Fig 446.



Oreodon gracilis.

Fig. 446 represents the skull of another Miocene Mammal, called an *Oreodon*, which is intermediate between the Deer, Camel, and Hog. Remains of a Camel and Rhinoceros, and some of the tapir-like beasts, have been found in the Miocene of the Atlantic border.

In the *Pliocene* beds of the Upper Missouri region still other species occur; including Camels, a Rhinoceros, an Elephant, a Mastodon, Horses, Deers, a Wolf, a Fox, a Tiger,—a range of species quite Oriental in character.

Among Mammals of the European Miocene there were *Elephants*, *Mastodons*, *Deer*, and

Fig. 447.

Dinotherium giganteum ($\times \frac{1}{10}$).

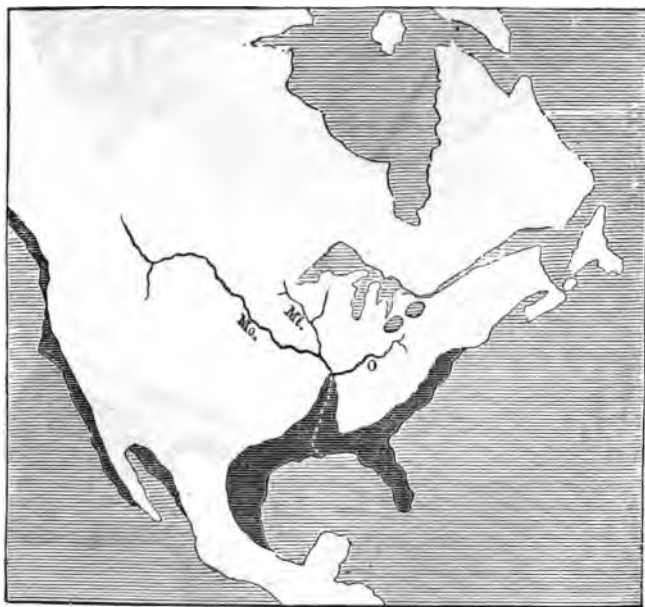
other Herbivores, many Carnivores, *Monkeys*, *Ant-eaters*, etc. One of the most singular species is the *Dinotherium*, the form of the skull of which is shown in Fig. 447; its actual length is 3 feet 8 inches. It appears to have had a proboscis like an Elephant, but the tusks proceeded from the *lower* instead of upper jaw, and were bent *downward*.

The earliest of the Bovine or Ox group occur in the European Pliocene.

4. General Observations.

1. **Geography.** — The Tertiary period completed mainly the work of rock-making along the borders of the continent, which

Figs. 448.



Map of North America in the early part of the Tertiary Period.

had been in progress during the Cretaceous period. The accompanying map shows approximately the part of the continent of North America under the sea toward the middle of

the Eocene Tertiary, or when the Lignitic period was near its close. By comparing it with the map of the Cretaceous continent, page 322, it is seen that in the interval the Rocky Mountain region had become dry land. The occurrence of brackish-water beds in the Lignitic Tertiary of the Upper Missouri region, and of salt-water beds, as well as brackish-water, in the Lignitic of the summit of the mountains, indicate, as shown by Hayden, that the passage from the marine condition of the Cretaceous era gradually changed into that of the fresh-water lakes and dry land of the later Eocene. The gradualness of the transition is further shown in the occurrence of Lignitic or coal-bearing beds in the Upper Cretaceous. After the Eocene, the elevation went forward, but still with extreme slowness, for in the Miocene the eastern slopes of the mountains were covered with immense fresh-water lakes, whose borders were the haunts of the Mammals of the era; and these lakes were continued, though of diminished size, into the Pliocene. The Cretaceous beds are now 10,000 feet above the sea-level, showing that this amount of elevation has taken place since that era; but this height may not have been fully attained before the closing part of the Pliocene period. The area of the Mississippi river-system, embracing the slopes of the Rocky Mountains on the west and those of the Appalachians on the east, then for the first time attained its full dimensions. The Mexican Gulf was much larger in the Eocene period than at present; but there was not that long extension northward which it had during the Cretaceous period. Florida was still submerged, and also all the bays of the Atlantic coast south of New York. After the Eocene epoch the Mexican Gulf became much more contracted by an elevation of the coast along the Gulf, accompanying which the part of Georgia northwest of Florida, where Eocene and Cretaceous beds had been formed in the sea, was raised 300 to 700 feet above the sea-level. By the close of the Tertiary period the continent appears to have reached nearly its present outline.

Besides the gradual changes, there was in the Rocky Mountain region, and also in California, the making of mountain ranges. At the close of the Lignitic period there were upturnings of the Lignitic and underlying formations; and the Wahsatch, with other high ranges in Colorado and the adjoining regions, are part of the results. Probably at the same time the Cretaceous strata of California, west of the Sierra Nevada, were made into mountains that are now part of the coast ranges. This then was one of the great mountain-making epochs in American Geological history.

In the Orient the Eocene era was one of very extensive submergence of the land, as shown by the distribution of the nummulitic beds over Europe, Asia, and Northern Africa, as stated on page 333. Before the close of the Eocene, the greater part of these Continental seas became dry land, and in general continued so afterward; for the marine Miocene and Pliocene are, comparatively, of limited extent. Many of the great mountains of the globe, as the Pyrenees, Alps, Carpathians, Himalayas, etc., received then a large part of their elevation, as is proved by their containing Eocene rocks in their structure, or by their bearing them about their summits. Thus it is learned that the elevation of the Pyrenees, though commenced before the close of the Cretaceous, was mainly produced in the middle or later part of the Eocene, as also that of the Julian Alps, the Apennines and Carpathians, and that of heights in Corsica. The Himalayas, in their western part about Cashmere, have nummulitic or Eocene beds, at a height of 16,500 feet; so that even this great chain, although earlier elevated to the east, was not completed before the Middle Eocene; and even later than this it received a considerable part of its elevation, as later Tertiary beds at lower levels show. The elevation of the Western Alps, including Mont Blanc, is referred by Elie de Beaumont to the close or latter part of the Miocene period; and that of the Eastern Alps, along the Bernese Oberland, to the close of the Pliocene. An elevation of 3,000 feet took place in Sicily after the Pliocene.

Many parts of the region of the Andes were raised 3,000 to 5,000 feet or more in the course of the Tertiary period.

Climite. — During the Eocene, Palms abounded in Britain, — evidence of a sub-tropical or warm-temperate climate in its latitudes; and the Arctic regions had forests consisting of Beech, Plantain, Willow, Oak, Poplar, Walnut, Magnolia, Redwood, showing a mean temperature of at least 48° F. (Heer.) In the *Miocene*, Southern Europe had a sub-tropical climate, but England had lost its palms and was cooler.

In North America, the *Eocene* palms and other plants of the Upper Missouri region show that the temperature of North Carolina characterized then the region of the Upper Missouri, the vicinity of the Great Lakes, and also Vermont, where exists the Brandon deposit of nuts and lignite.

The Camels, Rhinoceroes, and other animals of the *Pliocene* of the Upper Missouri, seem to prove that a warm-temperate climate prevailed there in that closing epoch of the Tertiary.

It is therefore plain that the Earth had not as great a diversity of zones of climate as now; and that Europe was little if any colder in the Eocene than in the Jurassic era. If the interval between the Cretaceous and Tertiary was one of unusual cold, through Arctic and other elevations, as suggested on page 328, the cold epoch had mostly passed when the Eocene era opened.

II. QUATERNARY AGE, or ERA OF MAN.

1. **General characteristics.** — The Quaternary age was remarkable (1) for *high-latitude* movements and operations both north and south of the equator; (2) for the culmination of the type of brute Mammals; and (3) for the appearance of Man on the globe.

2. **Periods.** — The periods are three: —

1. The *Glacial*, or the period when, *over the higher latitudes*, the continents underwent great modifications in the features of the surface through the agency of ice.

2. The *Champlain*, when the ice disappeared, and the same *high-latitude* portions of the continent, and to a less extent the lower, were *below* their present level, and became covered by extensive *fluvial* and *lacustrine* formations, and along sea-coasts by *marine* formations.

3. The *Recent* or *Terrace* period, begun by a rising of the land nearly or quite to its present level.

1. Glacial Period.

The following are some of the facts, characterizing the Glacial period :—

1. **Transportation.**—The transportation of a vast amount of earth and stones from the higher latitudes to the lower.

The transported material consists of earth, gravel, stones, and boulders, and includes, in America, nearly all the earth, as well as stones, of the surface in the latitudes of New England and farther north. It extends over hills and valleys, and varies in depth from a few feet to hundreds. A large part of the material is in an *unstratified* condition, large stones and small, pebbles and sand, being mingled pell-mell. Part, especially that in the valleys or depressions of the surface, is *stratified*, and thus bears evidence of deposition by flowing waters, like fluvial and lacustrine formations.

The transported material is called *Drift*, and the unstratified part of it *till* (from the Scotch). The till, especially its lower part, is often a clayey earth, or a clayey mixture of earth and stones with frequent boulders, called the *boulder-clay*; it is in general firmly compacted because of the clay. In the valleys the clay is often straticulate.

The drift-covered region of North America, or that over which the great southward movement took place, extends from the Atlantic border of New England and Labrador, westward, for more than 1,200 miles, Dakota and Lake Winnipeg being near the western border: but, farther north, it extends across the continent; and along the Rocky Mountains and the Pacific border spreads southward again.

The *southern limit* of travel for the *unstratified* drift, or till, is not fully made out. It is supposed to have had its course from Cape Cod (though perhaps lying miles outside of it) to Long Island and Perth Amboy, N. J.; through New Jersey northward and westward to Oxford; through Pennsylvania to a point north of Pittsburg; through Ohio, by Danville, to the Ohio east of Cincinnati; thence for a few miles in Kentucky; thence northwestward and westward through Middle Indiana and Illinois, and the States west, and to have included (Upham) the Coteau de Missouri in Dakota. The stratified drift (which is mostly a deposit of the Champlain period, as explained beyond) occurs much farther south along the river-valleys, and reaches even to the State of Mississippi in the Mississippi valley.

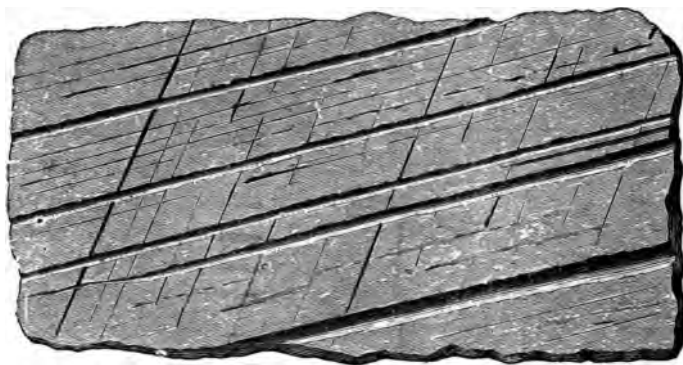
The travelled stones are of all dimensions, from that of a small pebble to masses as large as a moderate-sized house. One at Bradford in Massachusetts is 30 feet each way, and its weight is estimated to be at least 4,500,000 pounds. Many on Cape Cod are 20 feet in diameter. One lying on a naked ledge at Whitingham in Vermont measures 43 feet in length and 30 in height and width, or 39,000 cubic feet in bulk, and was probably transported across Deerfield Valley, the bottom of which is 500 feet below the spot where it lies. There are many great boulders of trap from 50 to 1,250 tons in weight along the western border of the Triassic-Jurassic area in Connecticut, the line reaching to Long Island Sound, just west of New Haven; and others of great magnitude occur farther south on Long Island.

The directions of travel, as learned by tracing the stones in numerous cases to the ledges whence they were derived, are, in general, between southwestward and southeastward. The distance to which the stones were transported in North America, as learned by comparing them with the rocks *in place* to the north, is mostly between 10 and 40 miles, though in some cases over 200 miles. The material was carried southward across the Great Lakes and across Long Island Sound —

the land to the south, in each case, being covered with stones from the land to the north.

Besides this *northern* Drift, there are similar accumulations of earth and stones belonging to the same era, distributed locally about some of the Appalachian ridges, south of Drift latitudes; also on a grand scale about the higher ridges of the summit of the Rocky Mountains, and in the Sierra Nevada and other ranges and heights of the Pacific border region.

Fig. 449.



Drift groovings or scratches.

2. **Scratches.**—The rocky ledges over which the drift was borne are often scratched, in closely crowded parallel lines, as in the preceding figure (Fig. 449), and planed off besides. The scratchings or groovings are sometimes deep and broad channellings, and at times a yard or more deep and several feet wide, as if made by a tool of great size as well as power. The scratches occur wherever the drift occurs, provided the underlying rocks are sufficiently durable to have preserved them, and they are usually of great uniformity in any given region. In some places two or more directions may be observed on the same surface. They are found in the valleys and on the slopes of mountains, to a height, on the Green

Mountains, of 4,400 feet, and on the White Mountains of 5,500 feet. They have nearly a common course over the higher lands of a region, and even cross slopes and the smaller valleys, without following the direction of the slope or valley; but they generally conform to the directions of the great valleys of the land, and often to the smaller when they have much breadth. In the Hudson River Valley, between the Catskills and Green Mountains, the scratches have mostly the course of the valley; and also in the Connecticut River Valley, the Merrimack, and other valleys.

The stones, or bowlders, of the till are often scratched as well as the rocks, and in this respect they differ from those of stratified drift; the latter have lost all scratches by river abrasion.

3. **European Drift.**—The Drift in Europe presents the same general course and peculiarities as in North America. It reaches south in some places to about latitude 50° . The region south of the Baltic, and parts of Great Britain, are covered with drift and stones from Scandinavia. The distance of travel varies from 5 or 10 miles to 500 or 600. About the Alps and other high mountains south of Drift latitudes there are *local* accumulations of Drift of the Glacial area, and also scratches over the surface rocks.

4. **Fiords.**—Fiords are deep, narrow sea-channels running many miles into the land. They occur on the coasts of Norway, Britain; of Maine, Nova Scotia, Labrador, Greenland; on the coast of Western North America north of the Straits of De Fuca; along that of Western South America south of latitude 41° S.

Fiords are thus, like the Drift, confined to the higher latitudes of the globe, the *Drift-latitudes*; and the two may have been of contemporaneous origin.

5. **Origin of the Drift.**—Nothing but moving ice could have transported the Drift with its immense bowlders.

Glacier Theory.—The ice is performing this very work now in the *glacier* regions of the Alps and other icy mountains,

and stones of as great size have in former times been borne by a slow-moving glacier from the vicinity of Mont Blanc across the lowlands of Switzerland to the slopes of the Jura Mountains, and left there at a height of over 2,000 feet above the level of Lake Geneva. Moreover, there are in many places deposits of boulder-clay, made of the earth formed by trituration of stones against stones during the moving of the glacier. Further, there are scratches, of precisely the same character as to numbers, depth, and parallelism, on the granitic and limestone rocks of the ridges; and besides, the transported material is left unstratified over the land, wherever it is not acted upon and distributed by Alpine torrents.

Icebergs also transport earth and stones, as in the Arctic seas; and great numbers are annually floated south to the Newfoundland banks, through the action of the northern or Labrador current, where they melt and drop their great boulders and burden of gravel and earth to make deposits over the sea-bottom. But icebergs could not have covered great surfaces so regularly with scratches. Again, there are no marine relics in the unstratified drift to prove that the continent was under the sea in the Glacial period.

There is a seeming difficulty in the glacier theory, from the supposed want of a sufficient slope in the surface to produce movement. But a slope in the under surface is not needed, any more than for the flowing of pitch. Pitch, deposited in continued supply on any part of a plain, would spread in all directions around; and this it would do if, instead of a plain, the surface beneath had an ascending slope. The slope of the *upper surface* of a plastic or fluid substance determines the rate of flow, not that of the under surface. Hence, if ice were accumulated over a region so that the *upper surface* had the requisite slope, there would be motion in the mass in the direction of this slope, whatever the bottom slope might be. At the same time the slope of the land *at bottom*, or the *courses of the valleys*, would determine to some extent the *movement at bottom*; just as oblique grooves in a sloping board, down

which pitch was moving, would determine more or less completely the direction of the movement in the grooves.

A semi-continental glacier. All the facts or phenomena connected with the northern Drift are fully explained by reference to a great northern semi-continental glacier as the cause; and those relating to local Drift about high mountains, south of Drift latitudes, by referring them to local glaciers. But icebergs drifted down the coast, and probably crossed the flooded region of the Great Lakes. Ice-floes descended rivers, dropping their stones by the way. On the Mississippi, the floating ice may have reached the Gulf of Mexico and the chilled waters have destroyed much tropical life.

The height to which scratches and drift occur about the White Mountains proves that the upper surface of the ice in that region was 6,000 or 6,500 feet; and hence that the ice was not less than 5,000 feet thick over that part of Northern New England. Facts also show that the surface height in southwestern Massachusetts was at least 2,800 feet; in southern Connecticut, 1,000 feet or more; in the Catskills, 3,000 feet (Smock).

Since the slopes of the upper surface of a glacier determine the general direction of movement, and therefore of transportation and abrasion, the lines of scratches or of drift are an indication as to the *position of the ice-summit*. The prevailing direction over the higher lands of New England and eastern Canada is *southeastward*, and that over western New York and Pennsylvania and the country north and northwest to Winnipeg Lake, is *southwestward*. The lines consequently converge northward, toward the part of the Canada water-shed west of north from Montreal and a region extending thence northeastward toward the Arctic regions; and hence along this course there must have been the summit of a great ice range. Farther west, over the dry interior of the continent (where the present amount of annual precipitation is only 12 to 20 inches), the ice thinned out or was absent.

It is consequently evident that the ice of the Glacial era

in America was not an ample "ice-cap" covering the northern latitudes nearly half way to the equator, but that the ice stretched southward from a polar area *along the courses of greatest atmospheric precipitation*; which courses were three in number: one of great width and height on the Atlantic side, the moist side of the continent; a second, of comparatively narrow limits, on the Pacific side; and a third, following the higher ridges of the Rocky Mountains.

The stones and earth transported by the Continental glacier were gathered up mostly by its lower part, from the surface of hills or ridges that projected into it, and even from the plains beneath it. In New England, where there were no peaks rising above the upper surface to be a source of avalanches, as in the Alps, many of the masses thus taken aboard exceed 1,000 tons in weight.

Excavating action of the Glacier.—With a thickness of even 2,000 feet the glacier would have had great excavating force, although the abrading power was not great. Soft rocks would have been deeply ploughed up by it, and all jointed and fissile rocks, soft or hard, would have been torn to fragments, and the loosened masses borne off. By this means, and most of all through the erosion of subglacial streams, valleys were excavated and widened.

Drift in other Countries.—The drift phenomena of Europe lead to the same general conclusion: that *amount of precipitation determined to a large extent the distribution of the ice*; temperature being the other chief condition. The southern limit is, on an average, 10° higher in latitude in Europe than in America, corresponding to the modern fact as to the climate of the region. The great European ice-range followed the course of the Scandinavian mountains, the moist mountain-border of Western Europe. The Alps, although outside of the area of northern drift, had glaciers over 2,000 feet above their present limit; and enormous bowlders from the Alps (one of 3,000 tons) lie high on the Juras, to the west of the plains of Switzerland. With such facts from the Alps, large

estimates as to the thickness of the ice in America lose their apparent extravagance. In Asia the precipitation was too small to make a glacier over the lower plains.

Greenland is at the present time a glaciated continent, nearly as northern America was in the Glacial era. The ice moves where the slope of surface is less than half a degree. In the Glacial era, the Greenland ice stood, in some parts of the Coast region, 3,000 feet above its present level; which is a small difference compared with the thickness of ice produced by the Glacial era in more southern and moister latitudes.

On the possible *origin of a glacial climate*, see page 125.

2. Champlain Period.

The Champlain period, as is proved by marine relics and by other facts described beyond, was an era of *depression in the continents* over the higher latitudes below the *present level*, and a depression which, within certain limits, increased to the northward. It was also a period, as indicated by the terrestrial life, of *warmer climate* than the Glacial; and, probably, because of the lower level of the northern or high-latitude lands. The warmer climate appears to have determined the melting of the great glacier, and it caused this melting to go on widely over its surface; so that, when it had thinned down the ice to within 500 or 1,000 feet, the disappearance of the rest of the ice went forward with accelerated progress.

(1) The *melting* was thus the great event of the opening part of the Champlain period; and it must have caused immense floods in all valleys, vastly beyond those from the breaking up of an ordinary winter.

With the melting of the lower 1,000 feet, and during the era of floods, there would have been (2) the *deposition* of the earth, gravel, and stones contained therein; and in the deposition, wherever the material fell over the land, it would have gone down pell-mell and been left (a) *unstratified*; while, whatever fell into flowing streams, lakes, tidal estuaries, or along sea-coasts, would have been (b) *stratified*. The stratified

deposits of the Champlain period are then either (1) of river-valley origin, (2) lacustrine, or (3) estuary or marine.

After the era of floods or the *Diluvial* part of the Champlain period, the depositions in what may be called the *Alluvial* part of the period went on more quietly; and many land shells, bones, and other relics are contained in the river-valley deposits then made.

The Diluvial beds consist of earth, clay, sand or pebbles, or of mixtures of these materials. And the Alluvial are partly the same, but more commonly of finer earth and clay.

The river-border deposits occur in all or nearly all the river-valleys within the drift latitudes of the North American continent, from Maine to Oregon and California; and they exist farther south, extending along the Mississippi Valley to the Gulf of Mexico. The cold water descended the valley in a vast flood to the Gulf, bearing on its surface much drift ice from the dissolving glacier, — the fact of the flood and that of the floating ice being proved, as Hilgard has shown, by the nature of the stratified deposits, and the occurrence of northern boulders, 100 to 150 pounds in weight at least, as far south as the State of Mississippi. Facts prove also that the cold waters and ice in the Gulf were destructive to the tropical life along its northern borders.

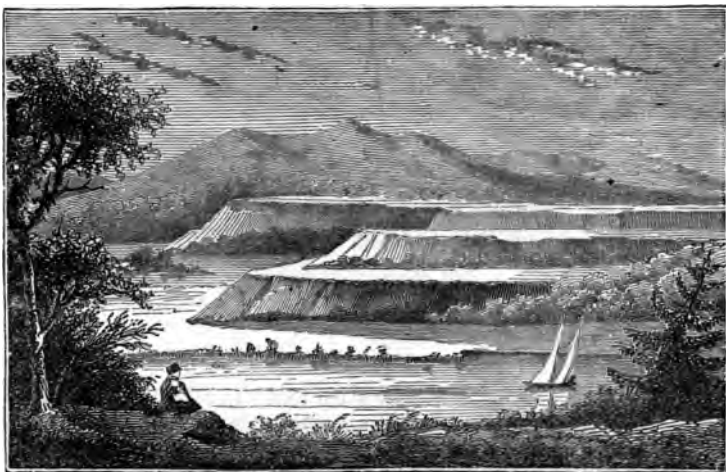
These river-valley deposits form at present elevated plains on one or both sides of the valley. Their elevation above the river is greater in Northern New England than in Southern; and there is, in general, a like difference between those of the northern and southern parts of the States west of New England; this height, in valleys remote from the coast, is mainly due to the height of the flood.

The view in Fig. 450 represents a scene on the Connecticut, a few miles below Hanover in New Hampshire, where there are three different levels, or terraces, in the alluvial formation; the upper shows the total thickness of the formation down to the river-level.

As the Glacial flood declined, the waters gradually fell below

the top of the flood-made valley formation, and in most cases far below it, leaving it as a high terrace plain, with sometimes one or more lower terraces (Fig. 450). The lower terraces may have been made by changes in the river as it subsided; or they may be only different levels of the bottom of the great flooded stream, like the flats at different depths in any broad river or bay. The main channel of the flooded stream was

Fig. 450.



Terraces on the Connecticut River, south of Hanover, N. H.

kept large and deep where the flow along the valley was most violent, and less deep where less violent. Terraces have often great height above a narrow gorge, because the waters were there dammed by floating ice or other means.

Terraces in river-valleys have sometimes resulted from an elevation of the land, this giving a stream greater pitch, and hence causing an excavation of its bed to a lower level. But examples of such are mostly confined to the parts of river-valleys toward the sea-coast.

In many places, the upper part of the terrace formation, for 10 to 40 feet, is coarsely stony, while underneath it usually consists of sandy, pebbly, or clayey layers. This overlying coarse bed shows that the flood, toward the close of the

glacier, was suddenly augmented in depth and violence. Such coarse beds occur where the flow was most violent, and they often top one of the lower terraces, these being low because of the violence of the flow over them.

The *lacustrine* deposits are of similar character to those of the valleys, and of like distribution over the continent; and they are equally elevated above the present level of the water they border.

The *sea-border* deposits, or those formed on sea-shores and estuaries, are found at many places on the coasts of New England, both the southern and eastern. At several localities in Maine they afford shells at heights not far from 200 feet above the sea-level. They form deposits of great thickness along the St. Lawrence, as near Quebec, Montreal, and Kingston; at Montreal they contain numerous marine shells at a height of 400 to 520 feet above the river. They border Lake Champlain, being there 393 feet in height above its level; and, besides marine shells, the remains of a *whale* have been taken from the beds.

In the Arctic regions similar deposits full of shells are common, at different elevations up to 600 or 800 feet, and in some places 1,000 feet, above the sea-level.

These sea-border deposits, now elevated, must have been at the water-level, or below it, when they were formed; that is, in the Champlain period. The facts prove that the river St. Lawrence was at that time an arm of the sea, of great breadth, with the bordering land 400 to 500 feet below its present level; that Lake Champlain was a deep bay opening into the St. Lawrence channel, and that it had its whales and seals as well as sea-shells; that the coast of Maine was in part 200 feet below its present level, and Southern New England 10 feet.

There is some reason for the opinion that the whole northern portion of the continent was less elevated than now; and also that the depression was greatest to the north, since the sea-border Champlain formations on both the Atlantic and Pacific sides are above the present sea-level, and at higher

elevations to the north, or near the northern boundary of the United States, than they are to the south.

The facts here stated with regard to elevated river-valley, lacustrine, and sea-border formations in North America have their parallel in Europe. In Great Britain the Glacial period was followed by one of depression, in which its northern portions were over 1,000 feet below their present level. The remarkable terraces or benches of Glen Roy, in Scotland, are three in number, and 1,139, 1,039, and 847 feet above the sea-level. In Sweden there are sea-border beds with shells very similar to those of Maine and the St. Lawrence; and facts prove that the White Sea was then connected with the Baltic, and possibly with the Caspian.

While, therefore, the facts relating to the *Glacial* period favor the view that the northern portions of the continents were then *raised above their present level*, those of the next or *Champlain* period suggest that they were afterward *below their present level*. If so, there was an *upward* high-latitude movement for the Glacial period and a *downward* for the Champlain period; and the latter movement brought to its close the era of ice, by occasioning a warm climate.

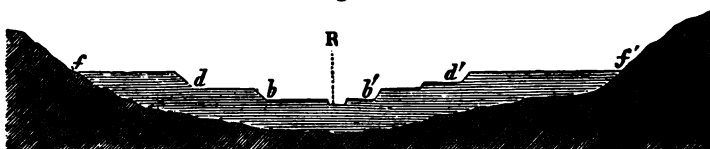
3. Recent Period.

When the Champlain period was in progress, the upper plain of the sea-border formations, now so elevated, was at the sea-level; and the high alluvial plains along the rivers were the flood-grounds of the rivers. The land has since been raised; and, consequently, the sea-border formations are now high above tide-level. Some of them were of beach origin, and the height of these equals nearly the amount of elevation; others were submerged mud-banks or sea-bottoms, as proved by their fossils, and these were carried up to a less height above the sea, according to their depth beneath its surface. The formations thus elevated often make a series of terraces or "benches" along a coast.

The elevation also led the rivers over the elevated region,

especially toward the coast, to erode their beds through the Champlain deposits of the valley to a lower level, and so make terraces on one or both sides, as represented in Fig. 451. But the terraces over the continent away from the coasts may be mainly due (p. 357) to the subsiding of the waters after the flood was at its height and had done its chief work of deposition, and only slightly, where at all, to this elevation.

Fig. 451



Section of a valley with its terraces completed.

As already stated, the sea-border formations of both sides of the continent are raised high above existing tide-level, and most so to the north. Hence, while the Champlain period was one of a low level in the continent, especially at the north (certainly along its coasts, and probably over its whole breadth), the Recent period began in a rising again, until the region before depressed reached its present height; and this rising was greatest at the north. It is hence probable that there were high-latitude oscillations in this part of geological history—an *upward* movement in the Glacial period, a *downward* in the Champlain period, an *upward* again in the Recent period; but how far such changes were general over the hemisphere is unknown. It does not appear that the movement resulted anywhere in the raising of a mountain-range.

In Europe there was a second Glacial era, in which the northern portions of that continent were again covered with ice, and glaciers spread anew from the Alps over part of Lower Switzerland. It appears to have occurred at the close of the Champlain period, and to have been connected with the rising of the land that introduced the Recent period,—the rising having carried the land above its present level. Proofs

of the occurrence of such an epoch are found in the remains of the Reindeer and other sub-arctic animals, in Southern France (page 369), in deposits that are subsequent in date to true Champlain deposits.

The Recent period is, hence, opened by this second Glacial epoch, while it closes with the modern or historical era.

Modern Changes of Level.

The sea, the rivers, the winds, and all mechanical and chemical forces are still working as they have always worked; and, too, the earth is undergoing changes of level over wide areas, although it has beyond question reached an era of comparative repose.

These changes of level are either *paroxysmal*, — that is, take place through a sudden movement of the earth's crust as sometimes happens in connection with an earthquake; or they are *secular*, — that is, result from a gradual movement prolonged through many years or centuries. The following are some examples: —

1. Paroxysmal. — In 1822 the coast of Western South America, for 1,200 miles along by Concepcion and Valparaiso, was shaken by an earthquake, and it has been estimated that the coast near Valparaiso was raised at the time 3 or 4 feet. In 1835, during another earthquake in the same region, there was an elevation, it is stated, of 4 or 5 feet at Talcahuano, which was reduced after a while to 2 or 3 feet. In 1819 there was an earthquake about the Delta of the Indus, and simultaneously an area of 2,000 square miles, in which the fort and village of Sindree were situated, sunk so as to become an inland sea, with the tops of the houses just out of water; and another region parallel with the sunken area, 50 miles long and in some parts 10 broad, was raised 10 feet above the delta. These few examples all happened within an interval of sixteen years. They show that the earth is still far from absolute quiet, even in this its finished state.

2. Secular. — Along the coasts of Sweden and Finland, on the Baltic, there is evidence that a gradual rising of the land is in slow progress. Marks placed along the rocks by the Swedish government, many years since, show that the change is slight at Stockholm, but increases northward, and is felt even at the North Cape, 1,000 miles from Stockholm. At Uddevalla the rate of elevation is equivalent to 3 or 4 feet in a century.

In Greenland, for 600 miles from Disco Bay, near 69° N., to the frith of Igaliko $60^{\circ} 43'$ N., a slow sinking has been going on for at least four centuries. Islands along the coast, and old buildings, have been submerged. The Moravian settlers have had to put down new poles for their boats, and the old ones stand "as silent witnesses of the change."

It is believed also that a sinking is in progress along the coast of New Jersey, Long Island, and Martha's Vineyard, and a rising in different parts of the coast-region between Labrador and the Bay of Fundy. There are deeply buried stumps of forest-trees along the sea-shore plains of New Jersey, and other evidences of a change of level (G. H. Cook.)

The above cases illustrate movements by the century, or those slow oscillations which have taken place through the geological ages, raising and sinking the continents, or at least changing the water-line along the land.

This fact is to be noted, that these secular movements of modern time over the continents are, for the most part, so far as observed, *high-latitude oscillations*, just as they were in the earlier part of the Quaternary.

Life of the Quaternary.

The invertebrate animals of the Quaternary, and probably also the plants, were very nearly if not quite all identical with existing species. The shells and other invertebrate remains found in the beds on the St. Lawrence, Lake Cham-

plain, and on the coast of Maine, are similar to those now found on the coast of Maine or Labrador, or farther north.

The life of the Quaternary of greatest interest is the Mammalian, which type, as regards brutes, culminated in the Champlain period. This culmination was manifested in—(1) the number of species, (2) the multitude of individuals, (3) the magnitude of the animals,—the period in each of these particulars exceeding the present time.

Along with the brute Mammals of the Quaternary appeared also Man.

I. Brute Mammals.

1. **Europe and Asia.**—The bones of Mammals are found in caves that were their old haunts; in Drift and stratified Champlain deposits along rivers and lakes; in sea-border deposits; in marshes, where the animals were mired; in ice, preserved from decay by the intense cold.

The caves in Europe were the resort especially of the Great Cave-Bear (*Ursus spelæus*), and those of Britain of the Cave-Hyena (*Hyaena spelæa*). Into their dens they dragged the carcasses or bones of other animals for food, so that relics of a large number of species are now mingled together in the earth, or stalagmite, which forms the floor of the cavern. In a cave at Kirkdale, England, portions of a very large number of Hyenas have been made out, besides remains of an *Elephant*, *Lion*, *Tiger*, *Bear*, *Wolf*, *Fox*, *Hare*, *Weasel*, *Rhinoceros*, *Horse*, *Hippopotamus*, *Ox*, *Deer*, and other species, all then inhabitants of that country. A cave at Gaylenreuth is said to have afforded fragments of at least 800 individuals of the Cave-Bear. The Cave-Hyena is regarded as a large variety of the *Hyaena crocuta* of South Africa, and the Cave Lion, a variety of *Felis leo*, the Lion of Africa. But many of the species are now extinct.

The fact that the numbers of species and of individuals in the Quaternary was greater than now, may be inferred from comparing the fauna of Quaternary Great Britain with that

of any region of equal area in the present age. The species included gigantic *Elephants*, two species of *Rhinoceros*, a *Hippopotamus*, three species of *Oxen*, two of them of colossal size, the *Irish Deer* (*Megaceros Hibernicus*), whose height to the summit of its antlers was 10 to 11 feet, and the span of whose antlers was in some cases 12 feet, *Deer*, *Horses*, *Wild Boars*, a *Wild-cat*, *Lynx*, *Leopard*, a *Tiger* larger than that of Bengal, a large *Lion* called a *Machærodus*, having sabre-like canines sometimes eight inches long, the *Cave-Hyena*, *Cave-Bear*, besides various smaller species.

Fig. 452.



Skeleton of *Mastodon giganteus*.

The Elephant (*Elephas primigenius*) was nearly a third taller than the largest modern species. It roamed over Britain, Middle and Northern Europe, and Northern Asia, even to its Arctic shores. Great quantities of tusks have been exported from the borders of the Arctic sea for ivory.

These tusks sometimes have a length of $12\frac{1}{2}$ feet. Near the beginning of the century one of these Elephants was found frozen in ice at the mouths of the Lena; and it was so well preserved that Siberian dogs ate of the ancient flesh. Its length to the extremity of the tail was $16\frac{1}{2}$ feet, and its height $9\frac{1}{2}$ feet. It had a coat of long hair. But no amount of hair would enable an Elephant now to live in those barren, icy regions, where the mean temperature in winter is 40° F. below zero. Siberia had also a hairy Rhinoceros.

Although there were many Herbivores among the Quaternary species of the Orient, the most characteristic animals were the great *Carnivores*. The period was the time of triumph of brute force and ferocity, and the Orient was especially the scene of its triumph.

2. **North America.**—In the Champlain period there were great *Elephants* and *Mastodons*, *Oxen*, *Horses*, *Stags*, *Beavers*, and some *Edentates*, in Quaternary North America, unsurpassed in magnitude by any in other parts of the world. *Herbivores* were the characteristic type. Of *Carnivores* there

Fig. 453.



Megatherium Cuvieri ($\times \frac{1}{3}$).

were comparatively few species; no true cavern species have been discovered. Fig. 452 (from Owen) represents the specimen of the American *Mastodon* now in the British Museum.

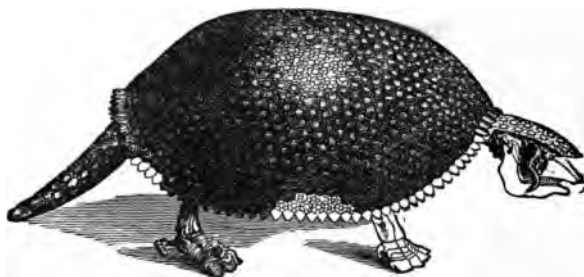
The skeleton set up by Dr. Warren in Boston has a height of 11 feet and a length to the base of the tail of 17 feet. It was found in a marsh near Newburgh, New York. The American *Elephant* was fully as large as the Siberian.

3. **South America.** — South America had, at the same time, its Carnivores, its Mastodons, and other Herbivores; but it was most remarkable for its *Edentates*, or animals related to the Sloths.

Fig. 453 shows the form and skeleton of one of these animals, — the *Megathere*. It exceeded in size the largest Rhinoceros: a skeleton in the British Museum is 18 feet long. It was a clumsy, sloth-like beast, but exceeded immensely the modern Sloth in its size. Another kind of Edentate had a shell like a turtle, and was somewhat related to the Armadillo. One of them is called a *Glyptodon* (Fig. 454). The animals of this kind were also gigantic, the *Glyptodon* here figured having had a length, to the extremity of the tail, of *nine* feet.

South America was eminently the continent of *Edentates*.

Fig. 454.



Glyptodon clavipes ($\times \frac{1}{3}$).

4. **Australia.** — Quaternary Australia, in the Champlain period, contained Marsupial animals almost exclusively, like modern Australia; but these partook of the gigantic size so characteristic of the Mammalian life of the period. One species, called *Diprotodon*, was as large as a Hippopotamus, and another, the *Nototherium*, was as large as an ox.

5. Conclusions.—The facts sustain the following conclusions:—

1. The Champlain period of the Quaternary was the culminating time of Mammals, both as to numbers and magnitude.

2. Each continent was gigantic in that type of Mammalian life which is now eminently characteristic of it: The Orient, in *Carnivores*, and, it may be added, also in *Monkeys*; North America, in *Herbivores*; South America, in *Edentates*; Australia, in *Marsupials*.

3. The climate of Great Britain and Europe, where were the haunts of *Lions*, *Tigers*, *Hippopotamuses*, etc., must have been warmer than now, and probably *not colder than warm-temperate*. The climate of Arctic Siberia was such that shrubs could have grown there to feed the herds of Elephants, and hence *could not have been below sub-frigid*, for which degree of cold it is possible the animals might have been adapted by their hairy covering.

4. The Champlain period, the meridian time of the Quaternary Mammals, was hence, as before stated, one of warmer climate over the continents than the present, and much warmer than that of the Glacial period. The species may have begun to exist before the Glacial period ended in Europe; but they belonged pre-eminently to the Champlain period, when the sinking of the land over the higher latitudes had introduced the warmer climate.

5. The larger part of the great Mammals of the Quaternary disappeared with the close of the Champlain period or in the early part of the Recent period, while others found refuge in the tropics. They were animals of a warmer climate than now belongs to the regions which they then inhabited; and the cold of the second Glacial era, with which the Recent period opened, probably brought about the extermination and forced migration.

Such an epoch of cold could not have been passed through by Europe without some refrigeration of the climate of North

America, since the two continents are bound together by a common Arctic. The remains of Reindeers have been found in Southern New York and near New Haven in Connecticut; but the latter, at least, were found in Champlain deposits, and are no evidence as to a second Glacial epoch.

Among the Mammals of Europe which existed before the close of the Champlain period, some are now living; as the *Reindeer*, *Marmot*, *Ibex*, *Chamois*, *Elk*, *Wild Boar*, *Goat*, *Stag*, *Aurochs*, *Urus*, *Wolf*, *Brown Bear*, and others.

2. Man.

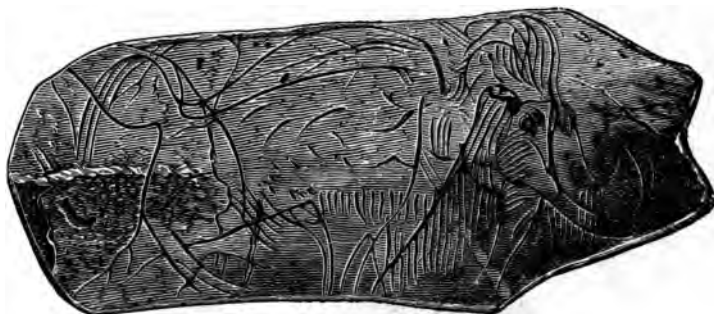
1. **Relics of Man.** — The earliest relics of Man in Europe are rude flint implements, as arrow-heads, chisels, etc.; flint-chippings, or the chips thrown off in making the implements; rude carvings; human bones and skeletons; the bones of the animals used for food, split lengthwise, this being done to get at the marrow; charcoal, and other remains of fires. They occur associated with the remains of the Cave-Bear, Cave-Hyena, Cave-Lion, Elephant, and other species. They date from the Champlain period, and perhaps, in part, from the earlier Glacial period.

2. **The Paleolithic Era.** — As the only implements of early Man in Europe were of stone, the era in human history has been called the "Stone age"; and this earliest part of that age, above referred to, has been designated the Paleolithic era, from the Greek *παλαιός*, *ancient*, and *λίθος*, *stone*. Portions of skeletons referred to this era have been found in Belgium, and some other countries. The Belgian skulls are "fair average skulls"; "the lowest yet discovered cannot be regarded," says Huxley, as "the remains of a human being intermediate between Man and the Apes." The stone implements are never polished, and are of ruder make than those of the later part of the Stone age.

3. **The Reindeer Era.** — The second section of the European Age of Stone has been called the Reindeer era. It was the time of the second Glacial epoch, and it is distinguished by

the occurrence of large numbers of the bones of the Reindeer in the caves of Southern France, along with the human relics. The flint implements of this era are well made, but unpolished; and among the relics there are implements of bone or horn, and drawings of animals upon these materials. One of these drawings from Southern France, made on ivory, is copied in Fig. 455. It represents the hairy Elephant of the

Fig. 455.

*Elephas primigenius*; engraved in ivory ($\times \frac{1}{2}$).

era. Remains of the Elephant, Cave-Bear, Cave-Hyena, Cave-Lion, occur in the same deposits, and also others of existing species, as the Elk, Ibex, Aurochs, Urus, etc. Perfect skeletons of man have been found in some of the caverns. Those of Southern France are in part of tall size,—5 feet 9 inches to 6 feet,—having well-shaped heads, and a large facial angle (85°). One, from a cave at Mentone (on the Mediterranean near the borders of France and Italy), was of a man full 6 feet in height; and it lay buried in the stalagmite of the cave, with flint implements and shell ornaments around, and a chaplet of stag's teeth across its head.

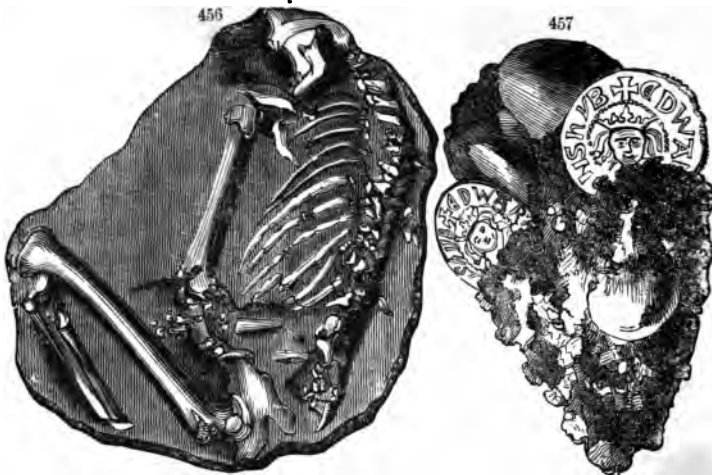
4. **The Neolithic Era.**—A third era is named the Neolithic (from *néos*, *new*, and *λίθος*). The relics are polished stone implements, broken pottery, bones of the dog. All remains of extinct Champlain Mammals and the Reindeer are absent. The race of men in Denmark resembled the Laplanders.

To later time in this era belong the earlier "lake-dwellings" of Switzerland, — structures built on piles in the lakes — in which the only implements are of stone. But in the later, about the western Swiss lakes, there are *bronze* implements, and these are of the "Bronze age."

In America, rude stone implements have been found (first by C. C. Abbot) in the stratified gravel near Trenton, N. J., which has afforded also Mastodon bones; testifying to the existence there of Man in the Champlain period, if not in the Glacial. The human skull reported from ancient gravels of Calaveras County, California, is still of doubted antiquity, and partly because so like a modern Indian's skull.

5. **Modern Human Relics.** — In still later deposits, buried coins, statues, temples, cities, are found among the earth's fossils, contrasting strangely with the remains of the species

Figs. 456, 457.



Human skeleton from Guadaloupe.

Conglomerate containing coins.

with which the history of the world's life began. Fig. 457 represents a *coin* conglomerate, containing coins of silver, of the reign of Edward I., found at a depth of ten feet below the bed

of the river Dove in England ; and Fig. 456, a portion of a human skeleton firmly imbedded in a modern shell-limestone of Guadaloupe, the former owner of which was two centuries since a fighting Carib.

6. **Man at the Head of the System of Life.** — With the creation of Man a new era in Geological history opens. In earliest time only *matter* existed, — dead matter. Then appeared *life*, — unconscious life in the plant, conscious and intelligent life in the animal. Ages rolled by, with varied exhibitions of animal and vegetable life. Finally Man appeared, a being made of *matter* and endowed with *life*, but, more than this, partaking of a *spiritual nature*. The systems of life belong essentially to time ; but Man, through his spirit, to the opening and infinite future. Thus gifted, Man is the only being capable of reaching toward a knowledge of himself, of nature, or of God. He is, hence, the only being capable of conscious obedience or disobedience of any moral law, the only one subject to degradation through excesses of appetite and violation of moral law, the only one with the will and power to make nature's forces his means of progress.

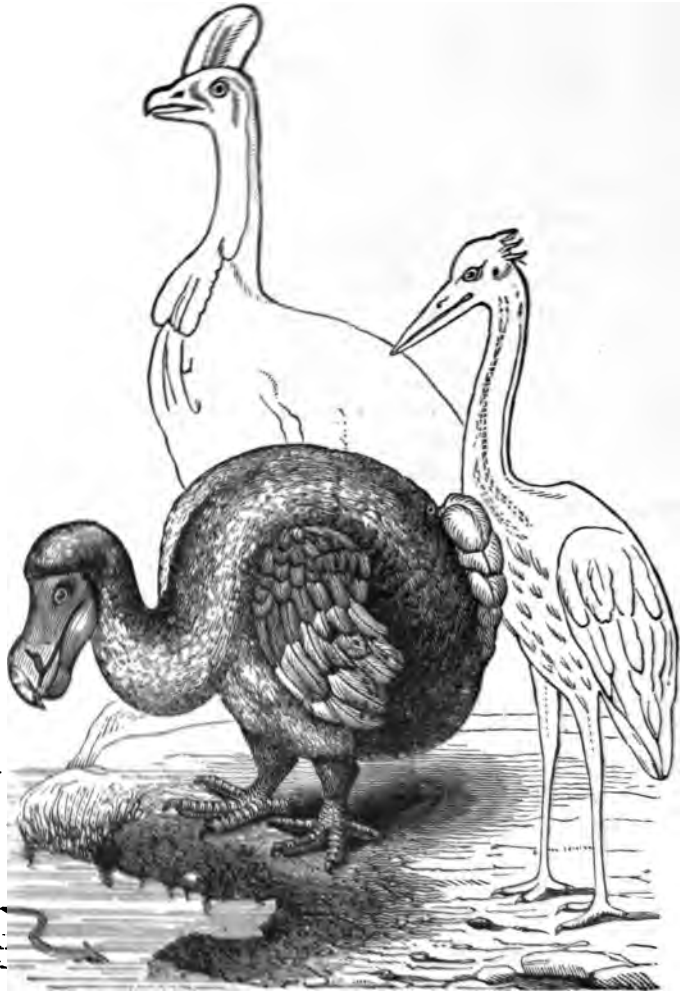
Man shows his exalted nature in his material structure. His fore-limbs are not made for locomotion, as in all quadrupeds ; they are removed from the *locomotive* to the *cephalic* series, being fitted to serve the head, and especially the intellect and soul. Man stands erect, his body placed wholly under the brain, to which it is subservient ; and his feet are simply for support and locomotion, and not, as in the Monkeys, grasping or prehensile organs for climbing. His whole outer being, in these and other ways, shows forth the divine feature of the inner being.

3. Extinction of Species in Modern Times.

Species are becoming extinct in the present era, as they have in the past. Man is now a prominent means of this destruction. The *Dodo*, a large bird looking like an overgrown chicken in its plumage and wings (Fig. 458), was abundant in

the island of Mauritius until early in the commencement of the eighteenth century.

Fig 458



Dodo, with the Solitaire in the background.

The *Moa* or *Dinornis* is a New Zealand bird of the Ostrich

kind that was living less than a century since; it was 10 or 12 feet in height, and the tibia ("drumstick") 30 to 32 inches long. In Madagascar remains of a still larger bird, but of similar character, occur, called an *Aepyornis*; its egg is over a foot ($13\frac{1}{2}$ inches) long. The *Auk*, a bird of Northern seas, has become extinct within the last 25 years; the last was seen in 1844. These are a few of the examples of the modern extinction of species.

The progress of civilization tends to restrict forests and forest-life to narrower and narrower limits. The Buffalo once roamed over North America to the Atlantic, but now lives only on the Rocky Mountain slopes west of the Missouri River. The beaver, wolf, bear, and wild-boar were formerly common in Britain, but are now wholly exterminated.

GENERAL OBSERVATIONS ON THE CENOZOIC ERA.

1. **Contrast between the Tertiary and Quaternary ages in geographical progress.** — The review of Cenozoic time has brought out the true contrast in the results of the Tertiary and Quaternary ages.

The Tertiary carried forward the work of rock-making and of extending the limits of the dry land southward, southeastward, and southwestward, which had been in progress through the Cretaceous period, and, indeed, ever since Archæan time.

The Quaternary transferred the scene of operations to the broad surface of the continent, and especially to its middle and higher latitudes.

Through the Tertiary the higher mountains of the globe had been rising and the continents extending; and hence the great rivers with their numerous tributaries — which are the offspring of great mountains on great continents — began to exist and to channel out the mountains and make valleys and crested heights. In the Glacial epoch this work went forward with special energy. The exposed rocks yielded

before the moving glacier, and the earth and boulders formed were taken up for distribution over the continental surface. Torrents, fed by the melting ice, were also at work, and with even greater abrading power than the ice. Thus the excavation of valleys and the shaping of hills and mountains were everywhere in progress. In the Champlain period, the low level at which the land lay, and the melting of the ice, with the dropping of its earth and stones, enabled the flooded streams to fill the great valleys deep with alluvium. In the Recent period, which followed, the upward movements of the land led to a completion of the terracing of the Champlain deposits along the sea-shores and about the lakes and rivers, and finished off the action of the rivers and vegetation in spreading fertility over the land.

Thus, under the rending, eroding, and transporting power of fresh water, frozen and unfrozen, — eminently the great Quaternary agent, — in connection, probably, with high-latitude oscillations of the earth's crust, the making of the earth was finally completed.

2. *Life*. — In the Cenozoic era, as in the preceding, species were disappearing and others took their places. The Mammals of the early Eocene are different in species from those of the later; and these from the Miocene, the Miocene from the Pliocene, and the Quaternary from the Pliocene.

According to the present state of discovery, Mammals commenced in the Mesozoic era, late in the Triassic period, and the Mesozoic species were all *Marsupials*. They were the precursor species, prophetic of that expansion of the new type which was to take place after the Age of Reptiles had closed. In the early Eocene, at the opening of the Age of Mammals, appeared Herbivores and Carnivores of large size. The Herbivores were mostly Pachyderms, related to the Tapir, Hog, and Rhinoceros, and distantly to the Stag. The true Stag family among Ruminants commenced in the Miocene; the Elephant tribe, in the Miocene; the Bovine or Ox family, in the Pliocene, or late in the Tertiary.

GENERAL OBSERVATIONS ON GEOLOGICAL HISTORY.

1. Length of Geological Time.

By employing as data the relative thickness of the formations of the geological ages, estimates have been made of the *time-ratios* of those ages, or their *relative* lengths (pages 269, 324). These estimated time-ratios for the Paleozoic, Mesozoic, and Cenozoic are 12 : 3 : 1. But the numbers may be much altered when the facts on which they are based are more correctly ascertained. It is quite certain that the first of the Paleozoic ages — the Silurian — was, at the least, four times as long as either the Devonian or Carboniferous ; and probable that Mesozoic time was not less than three times that of the Cenozoic.

Hence comes the striking conclusion that the longest age of the world since life began was the earliest, — when the earth numbered in its population only Radiates, Mollusks, and Marine Articulates, and, toward its close, Fishes. And the time of the earth's beginnings before the introduction of life must have exceeded in length all subsequent time.

The *actual* lengths of these ages it is not possible to determine even approximately. All that Geology can claim to do is to prove the general proposition that *Time is long*. If time from the commencement of the Silurian included 48 millions of years, which some geologists would pronounce much too low an estimate, the Paleozoic part, according to the above ratio, would comprise 36 millions, the Mesozoic 9 millions, and the Cenozoic 3 millions.

One of the means of estimating the length of past time is that afforded by the rate of recession of the Falls of Niagara. The river below the Falls flows northward in a deep gorge, with high rocky walls, for seven miles, toward Lake Ontario. It is reasonably assumed that the gorge has been cut out by the river, for the river is annually making progress of this

very kind. From certain fossiliferous Quaternary beds over the country bordering the present walls, and other evidence, it is proved that the present gorge, about six miles long, was made after the middle of the Champlain period. The present annual progress of the gorge from the cutting and undermining action of the waters has been variously estimated from *three feet a century* to *one foot a year*. At the larger estimate of one foot a year, the six miles would have required 31,000 years; or double this if six inches a year, as made by one observer; and if the estimate be one inch a year, or $8\frac{1}{2}$ feet a century, the time becomes nearly 380,000 years. The calculation may be regarded as establishing, at least, the proposition that *Time is long*, although it affords no satisfactory numbers. Other modes of calculation fully establish this general proposition.

2. Geographical Progress in North America.

The principal steps of progress in the continent of North America are here recapitulated:—

1. The continent at the close of the Archæan lay spread out mostly beneath the ocean (map, page 199). Although thus submerged, its outline was nearly the same as now. The dry land lay mostly to the north, as shown on the map. The form of the main mass approximated to that of the letter V, and it had a southeast and a southwest border nearly parallel to its present outline.

2. Through the Paleozoic ages, as the successive periods passed, the dry land gradually extended itself southward owing to a gradual emergence: that is, the sea-border at the close of the Lower Silurian was probably as far south as the Mohawk Valley in New York; at the close of the Upper Silurian it extended along not far from the north end of Cayuga Lake and Lake Erie; and by the close of the Devonian age the State was a portion of the dry land nearly to its southern boundary. This progress southward of the sea-

border in New York may be taken as an example of what occurred along the borders of the Archæan, to the westward. In other words, there was through the Silurian and Devonian ages a gradual *southerly* extension of the dry part of the continent, — that is, to the southeastward and the southwestward.

By the close of the Carboniferous age, or before the opening of the Mesozoic era, the dry portion appears to have so far extended southwardly as to include nearly all the area *east* of the Mississippi and north of the Gulf States, along with a part of that *west* of the Mississippi, as far nearly as the western boundary of Kansas.

3. Before the Silurian age began, and in its first period, great subsidences were in progress along the Lake Superior region, when the thick Huronian and Potsdam formations were made. The facts show that the depression of the lake, and probably that of some of the other great lakes, and also that of the river St. Lawrence, began to form either during the closing part of the Archæan age or in the early part of the Silurian age.

4. During the Paleozoic ages, rock-formations were in progress over large parts of the submerged portions of the continent up to the sea-borders, and some vast accumulations of sand were made as drifts or dunes over the flat shores and reefs. These rock-formations had in general *ten times the thickness along the Appalachian region* which they had over the interior of the continent; and they were mostly *fragmental deposits* in the former region, while mostly *limestones* in the latter. Hence two important conclusions follow:—

First. The Appalachian region was through much of the time an exposed shore-reef or flat of great extent, parallel in course with the present sea-border as well as that of the ancient Archæan area; while the interior was a shallow sea opening southward freely into the Gulf of Mexico, and only during some few of the periods with the same freedom eastward directly into the Atlantic. Most of the western part

of the sea (west of Missouri) appears to have been too deep for deposits between the Lower Silurian and Carboniferous eras.

Secondly. The Appalachian region was undergoing, through the Silurian and Devonian ages, great changes of level, the deposits having been made in shallow waters; the region was slowly sinking, not faster than the rate of deposition, and the amount of subsidence exceeded by ten times that in the Interior Continental region.

5. Of this Appalachian region, the Green Mountain portion was upturned, rendered metamorphic, and elevated above the ocean's level, at the close of the Lower Silurian; and at the same time the valley of Lake Champlain and Hudson River was formed, if not earlier begun.

This valley and the depressions of the Great Lakes, and also those of the lakes extending in a line through British America northwestward from Lake Superior to the Arctic regions, lie not far from the borders of the Archæan continent, and, therefore, between the portion of the continent that was comparatively stable dry land from the time of the Archæan onward, and that portion which was receiving rock-formations and undergoing oscillations of level. To this they appear to owe their origin.

6. As the Paleozoic era closed, an epoch of revolution occurred, in which the rocks of the *Appalachian* region south of New York and west of the Blue Ridge underwent (1) extensive flexures or foldings; (2) immense faultings in some parts; (3) consolidation, and, in some eastern portions, crystallization or metamorphism, with the loss of bitumen by the coal-beds changing them into *anthracite*. These changes affected the region from New York to Alabama. The effects of heat and uplift were more decided toward the Atlantic than toward the interior, showing that the force producing the great results was exerted in a direction from the Atlantic inland, or from the southeast toward the northwest. The Alleghany Mountains were then made; and they were, consequently, in existence when the Mesozoic era opened.

These mountains are parallel to the eastern outline of the original Archæan continent.

Similar changes may have taken place on the Pacific side ; but the facts thus far observed are opposed to such a conclusion.

This epoch of revolution was a time of mountain-making also in Europe.

7. In the early or middle Mesozoic period (the continent being largely dry land, as stated in the latter part of § 2), long depressions in the surface of the continent, made in the course of the Appalachian revolution and situated between the Appalachians and the sea-border, were brackish-water estuaries, or were occupied by fresh-water marshes and streams ; and Mesozoic sandstone, shale, and coal-beds were formed in them. The Connecticut Valley region of Mesozoic rocks (page 285) is one example. At the same time there were formations in progress over the Rocky Mountain region, a vast area from which the sea was not excluded, or only in part. At the close of the Jurassic period, the Sierra Nevada, and some other great ranges on the western side of the continent were made.

8. In the later Mesozoic, or the Cretaceous period, the continent had its Atlantic and Gulf border yet under water, and Cretaceous rocks were formed about them, and thus the continent continued its former course of enlargement south-eastward (see map, page 320). The *Western Interior* sea, opening south into the Gulf of Mexico, just alluded to, still existed, and deposits were made in it over a very large part of the great region reaching from Kansas on the east to the Colorado on the west and north perhaps to the Arctic Ocean. The Pacific border was also receiving an extension like the Atlantic.

9. In the early Cenozoic, or the Tertiary age, the extension of the Atlantic and Pacific borders was still continued. With its close the progress of the continent in rock-making south-eastward and southwestward was very nearly completed.

After the Eocene era had in part passed, at the close of the Lignitic period, there was the making of the Wahsatch Mountains and other ranges in the Rocky Mountain region, and of Coast ranges, west of the Sierra Nevada in California.

The *Western Interior* sea became greatly contracted after this last mountain-making epoch by the progressing elevation of the Rocky Mountain region, and the Mexican Gulf reduced greatly in size (map, page 345). During the middle of the Eocene Tertiary, the Ohio and Mississippi emptied into an arm of the Gulf just where they now join their waters; at the close of the Eocene the Ohio had taken a secondary place as a tributary of the Mississippi. The great Missouri River, the real trunk of the Interior river-system rather than the Mississippi, began its existence after the Cretaceous period, and reached its full size only toward the close of the Tertiary, when the Rocky Mountains finally attained their full height.

10. The elevation of the Rocky Mountains, like that of the Appalachians, was the raising of the land along a region *parallel* with the outline of the original Archæan dry land (see map, page 199). The elevation of the Sierra Nevada of California was a doubling of this same line on the west; while the elevation of the trap ridges and red sandstone of the early Mesozoic along the Atlantic border (page 286) was a doubling of the line on the east; finally the elevation of the Cretaceous with the Lignitic Tertiary tripled the line of heights on the Pacific side; and the later elevation of the Miocene added a fourth line of heights to the border of the great Pacific Ocean.

11. The continent being thus far completed, as the Quaternary Age was drawing on, operations changed from those causing southern extension to those producing movements of ice and fresh waters over the land, especially in the higher latitudes; and thereby valleys, great and small, were excavated over the continent; earth and gravel were transported and made to cover deeply the rocks and spread the continent with fertile plains and hills; and, as the final result, those grand features and those qualities of surface were deduced that were requisite to make the sphere a fit residence for Man.

3. Progress of Life.

1. Fact of progress of life. — Life commenced, among plants, in *Sea-weeds*; and it ended in *Palms, Oaks, Elms, the Orange, Rose, etc.* It commenced among animals in *Lingulæ* (Mollusks standing on a stem like a plant), *Crinoids, Worms, and Trilobites*, and probably earlier in the simple systemless *Protozoans* (page 185); it ended in *Man*. Sea-weeds were followed by *Lycopods, Ferns*, and other *Flowerless* plants, and by *Gymnosperms*, the lowest of *Flowering* plants; these finally by the higher *Flowering* species above mentioned, the *Palms and Angiosperms. Radiates, Mollusks, and Articulates*, which appeared in the early Silurian, afterwards had *Fishes* associated with them; later, *Reptiles*; later, *Birds* and *inferior Mammals*; later, *higher Mammals*, as *Beasts of prey* and *Cattle*; lastly, *Man*.

2. Progress from marine to terrestrial life. — The Silurian was eminently the *marine* age of the world. The plants found fossil in the Silurian until near its close are sea-weeds, and the animals all marine. The animals of the Devonian, also, are largely marine; but there is a step taken in terrestrial life by the expansion of the type of land-plants, and the appearance of Insects.

In the Carboniferous age, and through the Mesozoic era, the continents, or large areas over them, underwent alternations between a submerged and a dry land state, leading a kind of amphibian existence. The Carboniferous age had, besides its aquatic life, Insects, Spiders, Centipedes, terrestrial Mollusks, Amphibian and other Reptiles, and a great profusion of forest-trees and other terrestrial vegetation. In the Mesozoic, to Reptiles were added Birds and Mammals, eminently terrestrial kinds of life.

The Cenozoic was distinctively a continental era. The continents became mostly dry land after its earliest period; and, as the Age of Man approached, they had their full size and their present diversities of surface and climate. With

the increased variety of conditions fitted for terrestrial life there was, beyond question, a great augmentation in the number and variety of terrestrial species. Birds and Insects have probably their greatest numbers and variety of species in the present age. Marine species still abound, but relatively to the terrestrial they are far less numerous and less extensively distributed than in the Mesozoic and earlier ages.

3. Progress was connected with a constant change of species, new species appearing as others disappeared.—No species of animal survived from the beginning of life on the globe to the present time, nor even through a single one of the several geological ages; and but few lived on from the beginning of any one of the many periods to its close, or from one period into another.

There were widespread exterminations, closing some of the ages, as the Carboniferous and the Reptilian; there were less general exterminations, closing the periods on each of the continents; and others, still less general, at intermediate epochs; and often some disappearances accompanied each change in the rock-depositions that were in progress. For, in passing from one bed to another above, some fossils fail that occur below; and from the strata of one epoch to another, still larger proportions disappear; and sometimes with the transitions to rocks of another period or age, very nearly all the species are different. The rocks of the continents, that are open to examination, were made in Continental seas and the borders of the oceans adjoining; and hence their testimony with reference to exterminations does not extend to the Oceanic areas.

Of all genera of animals now having living species, only one, the Molluscan genus *Discina*, had species also in the earliest Silurian, unless the *Lingulellæ*, of the Primordial, were, as formerly supposed, true *Lingulæ*. Every other genus of that early time sooner or later numbered only extinct species. Afterward in the Lower Silurian, *Nautilus* and a few others were added to *Discina*.

Such unbroken lines prove the oneness of plan or system through geological history.

Nearly fifteen hundred species of Trilobites have been found fossil in the Paleozoic rocks, and in later formations none. Over 1,000 species of the Ammonite group occur in the Mesozoic rocks, — the last then, or in the early Tertiary, disappeared. 500 species of the Nautilus tribe have been in existence: now there are but two or three. Over 1,000 species of Ganoids have been found fossil: the tribe is now nearly extinct. The remains of 2,500 species of plants and over 40,000 species of animals have been found in the rocks, not one of which is now in existence. Thus the old has been ever passing away. But the number of kinds of *fossils* discovered cannot be the number of species that have existed; and the above numbers of marine species may safely be multiplied by *ten*, and of terrestrial by a *thousand*.

4. Progress not always begun by the introduction of the lowest species of a group. — Mosses, although inferior to Lycopods and Ferns, appear to have been of later introduction, for no remains have been found in the Carboniferous or Devonian rocks, although there are relics of both of the other tribes of plants.

The earliest of Fishes, instead of being those of lowest grade, were among the highest: they were Ganoids, or reptilian Fishes. Trilobites, found in the first fauna of the Silurian, are not the lowest of Crustaceans. No fossil Snakes have been found below the Cenozoic, although large Reptiles abounded in the Mesozoic. Oxen date from the later Tertiary, long after the first appearance of many higher Mammals, as *Tigers*, *Dogs*, *Monkeys*, etc.

There was upward progress in the grand series of species, as stated on page 381; but there was not progress in all cases from the lowest species to the highest.

5. The earliest species of a group were often those of a comprehensive type. — The *Ganoid* fishes are an example of these *comprehensive* types. As stated on page 238, they were *in-*

intermediate in some respects between Fishes and Reptiles; they were fishes *comprehending* in their structure some Reptilian characters, and hence called *comprehensive* types.

The earliest Mammals were *Marsupials*, or species of Mammals *comprehending* in their structure some characteristics of *oviparous* Vertebrates (see page 176), and, therefore, in certain respects intermediate between Mammals and Oviparous Vertebrates.

The vegetation of the coal-era consisted largely of trees allied to the Lycopods or Ground-pine of the present day; and these, as well as the Lycopods, constitute a type intermediate in some points between Ferns and Pines or Conifers (page 233).

In the Mesozoic the most characteristic plants were Cycads; and these comprehended in their structure something of *three* distinct types. They are closely like Conifers in structure and fruit; but they are like Ferns in the way the leaves unfold and in some other points, and like Palms in their foliage (page 288).

These comprehensive types embraced in their natures usually the features of some type that was to appear in the future. Thus, the Ganoid fishes of the Devonian foreshadowed the Amphibians, the first fossils of which occur afterward in the early Carboniferous.

6. Harmony in the life of a period or age.—Through the existence of these *comprehensive* types, and also in other ways, there was always a striking degree of harmony between the species making up the population—or the fauna and flora—of each period in the world's history.

Among the plants of the Carboniferous age there were—(1) the highest of the Cryptogams, or Flowerless plants, the Ferns; (2) the lowest of Phenogams (Gymnosperms), or Flowering plants, species having only inconspicuous and imperfect flowers, and hence *almost flowerless*; and (3) the *intermediate* types of Lycopods (Lepidodendrids and Sigillarids).

Again, in the Mesozoic the terrestrial Vertebrate life in-

cluded — (1) Reptiles, which are *oviparous* species ; (2) Birds, also *oviparous* species ; (3) reptilian Birds, having long tails like the Reptiles, and in part, at least, true teeth, — a comprehensive type ; (4) Reptiles that had the hollow leg-bones, and the biped locomotion, of birds, with some other bird-like characteristics ; (5) *semi-oviparous* Mammals, or Marsupials, an intermediate type between ordinary Mammals and the *oviparous* Reptiles and Birds.

7. Causes of the extinction of species and tribes. — 1. Some species of plants and animals require dry land for their support and growth ; some, fresh-water marshes or lakes ; some, brackish water ; some, sea-shore or shallow marine waters ; some, deeper ocean-waters.

Hence (a) movements in the earth's crust submerging large Continental areas, or raising them from the condition of a sea-bottom to dry land, would exterminate life : sinking them in the ocean, extinguishing *terrestrial* life ; raising them from the ocean, extinguishing *marine* life. In early times, when the Continental surface was in general nearly flat, a change of level of a few hundred feet, or perhaps of even 100, would have been sufficient for a wide extermination. If a modern coral island were to be raised 150 feet, its reef-forming corals would all be killed ; or if sunk in the ocean 150 feet, the same result would follow, — because the species do not grow below a depth of 100 feet. And if all the coral-reefs of the Pacific were simultaneously sunk or raised to the extent stated, there would be a total extinction of a large number of species.

(b) Along a sea-coast, the bays and inlets sometimes are closed by barriers thrown up by the sea, and hence become fresh, killing all *marine* life. Again, barriers are often washed away by the sea, and then salt water enters, destroying *fresh-water* life.

2. Species also endure a limited range of temperatures : some are confined thereby to the equatorial regions only ; some, to the cooler part of the tropical zone ; some, to the

warmer temperate latitudes ; some, to the middle temperate ; some, to the colder temperate ; some, to the frigid zone ; and few species live through two such zones. So also, for the same reason, they are confined to specific ranges of height above the sea-level ; or of depths below the ocean's surface.

Hence, (*a*) as the earth has gradually cooled in its climates from a time of universal tropics to that of the present condition, the larger part of those tribes or families that were fitted for the earlier condition of the globe in the course of time became extinct.

Again, (*b*) any temporary change of climate over the globe — from cold to warm or warm to cold — would have exterminated species. An increase in the extent and height of Arctic lands would have increased the cold directly, besides shutting out from the northern seas the warm currents of the oceans ; and thereby cold winds would have been sent south over the continents, and cold oceanic currents south along the borders of the oceans, or the Continental seas. This cause is one capable of carrying destruction over the Occident and Orient simultaneously.

On the contrary, a diminution in the extent of Arctic lands, making the higher regions open seas, and opening the Arctic to the warm currents of the oceans, or an increase in the extent of tropical lands for the sun to heat, would have increased the heat of the globe and sent a warm climate far north.

Such changes are destructive to living species. It is suggested on page 329 that the destruction of life at the close of the Mesozoic may have arisen from the cause here explained.

3. Any cause that in past time led to variations in species tended to obliterate old characteristics and introduce those that were new.

8. A parallelism between the progress in the system of life and the development from the embryo or young state of a species. — The young gar-pikes (Ganoids) of North American waters have

a vertebrated tail; and so it was with the Gars of the young world. The young of the higher Crustaceans, Shrimps, Lobsters, and Crabs, are very similar,—strangely similar, it might be said by one not familiar with the generality of Nature's laws,—to many Crustaceans of the young world, that is, of its earliest age after life began. Again, the young of the higher Insects are grubs and caterpillars; and these are related in important respects to Worms, the lowest of Articulates and the kind that long preceded Insects. This principle, announced by Agassiz, might be illustrated by examples from all departments of the animal kingdom.

9. Progress always the gradual unfolding of a system. — Man the culmination of that system. — There were higher and lower species appearing through all the ages, but the successive populations were still, in their general range, of higher and higher grade; and thus the progress was ever upward. The type or plan of vegetation, and the four grand types or plans of animal life, the Radiate, Molluscan, Articulate, and Vertebrate, were each displayed under multitudes of tribes and species, rising in rank with the progress of time, and all under relations so harmonious and so systematic in their successions that they seem like the expression—in material living forms—of one divine purpose. A scheme carried forward by infinite wisdom should exhibit, through each step of its progress, that complete adaptation to external conditions which pervades the actual system of Nature, and could result in no other than this very system. Its progress, if by divine power, should be, as zoölogical history attests, a development, an unfolding, an evolution.

With every new fauna and flora in the passing periods, there was a fuller and higher exhibition of the kingdoms of life. Had progress ceased with the Reptilian age, the system might have been pronounced the scheme of an evil demon. But, as time moved on, higher races were introduced; and finally Man came forth,—not in strength of body, but in the majesty of his spirit; and then living nature was full

of beneficence. The system of life, about to disappear as a thing of the past, had its final purpose fulfilled in the creation of a spiritual being, — one having powers to search into the depths of nature and use the wealth of the world for his physical, intellectual, and moral advancement, that he might thereby prepare, under divine aid, for the new life in the coming future.

Thus, through the creation of Man completing the system of life, all parts of that system became mutually consistent and full of meaning, and Time was made to exhibit its true relation to Eternity.

10. The progress in the system of life, a progress in cephalization. — A frog in the young state is a tadpole; that is, has a long tail behind, and outside gills either side of the head, and it is hardly above the lower fishes in grade. On passing to the adult state, the body is shortened in behind by the loss of the tail, the fish-like gills are dropped off from the head, and, simultaneously, the anterior or head extremity becomes vastly improved in its structure and functions. This transfer of forces anteriorly marked in abbreviation behind and improvement in the rest of the animal, especially in the organs of the head, that is, cephalically (the Greek *κεφαλή* meaning *head*), is an example under the principle of *cephalization*. There is similar headward progress in all development from the young state, whatever the class of animal; and in Man, at the head of the system, many years pass before the structure has the degree of cephalization that belongs to maturity. In a fly, the young, a maggot, is much like a worm, the body consisting of a number of similar segments and the head extremity little superior to the opposite. But in the *adult* fly, this extremity has its well-constructed head and senses, and the posterior extremity, besides being reduced in relative size, aids no longer in locomotion; the development is, in a wonderful degree, a cephalization of the structure. Such examples of the principle of cephalization are afforded by every part of the animal kingdom.

The principle is exemplified, also, in the relations of the inferior species of a group to the higher. A Lobster and a Crab (both Decapod Crustaceans) are essentially alike in fundamental points of structure. The Lobster has a very large and powerful tail (abdomen), a long and loosely compacted head, and also large and spreading head-organs; while the Crab, much the higher species, has the tail reduced to a small, feeble organ, hid away in a groove under the thorax, and, at the same time, the head and the organs of the senses and mouth connected with it are closely compacted. Abbreviation behind, and compacting and improvement in front, connected with differences of grade, are here well displayed.

Thus grade among the species of a group is marked by differences in the degree of cephalization of the structure; and this is so through all groups.

If, then, difference in grade among species is manifested in difference in cephalization, and if also the stages in the development of a species mark progress in cephalization, it is plain that the scheme of progress for the animal kingdom involved throughout progressing cephalization. In geological history there were vertebrate-tailed Ganoids before the non-vertebrate-tailed, tailed Amphibians and Birds before the tailless, Worms before the compact and highly cephalized Insect, Shrimps and Lobsters before Crabs; and so in other branches of the Animal Kingdom. In Man, the last term in the series, cephalization reached its extreme limit.

The system of progress hence involved also changes in animal structures. An animal with the high senses of an Insect could not have the form of a Worm; or those of a Crab, the form of a Lobster; or those of Man, the body or head of a Monkey.

11. Were the intervals between species or groups in the succession, through past time, abrupt, or gradual? — As Geology is the history of the progress of the earth and its life, the science is naturally looked to for a decision of the great question, Whether, in the succession of species during past time, there

were gradual transitions between them or not. Its testimony could not, however, be decisive, unless the record, in some parts at least, were a nearly unbroken one.

There is abundant evidence that, to a large extent, it is, as has been claimed, a *very broken* record. For example: there is not, on the eastern half of North America, the Atlantic border included, a species of the marine Molluscan or Radiate life of that border during the long Triassic and Jurassic periods. That there were abundant species in the seas is evident from the rocks of these eras in Europe. Coast deposits on the Atlantic must have been made; but they are out of reach beneath the ocean's waters. Again, two jaw-bones of *one* species of Marsupial Mammal are all the relics that have been found of these animals in rocks of the North American Triassic, Jurassic, and Cretaceous periods, or the whole of Mesozoic time; and yet, if there were one species in the Triassic, and two individuals, there were probably a large number of species, and multitudes must have lived and died through the Mesozoic era. In Europe, one single specimen of a bird has been found in Jurassic rocks, out of the myriads of individuals and the great numbers of species that must then have lived. Only a very few kinds of plants have been found in the Mesozoic formations of North America, and yet, the continent must have been buried in foliage through all the successive periods after the Carboniferous age.

It has to be admitted that we know very little about the past terrestrial life of the globe, and also that there are some great breaks in the succession of marine life. Moreover, breaks, as geological history shows, may exist where the rocks follow one another consecutively without any apparent interruption.

Now, in the succession of species made known by geology, the transitions connecting species or groups are abrupt, and not gradual. Some of the links between genera have been partially filled out by recent discoveries, as, for instance, that between the modern Horse and the Tapir-like Mammals of

the Eocene (page 341), and that between the Elephant and the Mastodon, etc. ; but still the species and genera of Horses stand apart. In the long geological succession of groups there are even fewer examples of blendings than occur in existing life.

Yet it has to be admitted that the above facts with regard to the breaks in the series of rocks weaken greatly this evidence against gradual transitions. And its force is further lessened by the fact that geological exploration has not extended to all parts of the world, or exhausted discovery in the portions that have been investigated. This is especially true of the *terrestrial* life of the globe ; but not so strongly with regard to the *marine* life, particularly the Paleozoic part, since the rocks of the earlier ages are mainly of marine origin, and abound in fossils.

There are still some breaks that are most remarkable, whatever allowance be made for imperfection of records. (1.) Trilobites and Brachiopods come abruptly into geological history with no recognizable traces of their antecedents. (2.) Fishes, the first of Vertebrates, appear in the later Silurian, with no species between them and the Invertebrates as their precursors. (3.) The leaves of Angiosperms (or trees of modern tribes related to the Willow, Elm, Magnolia) and also the Palms, are found fossil in the Cretaceous rocks of the continents, and none whatever as yet in the Jurassic.

The Triassic rocks have afforded bones of the first Mammals, — Marsupial Mammals ; but nothing with regard to the line of predecessors connecting them with inferior oviparous species. The Tertiary rocks of all the continents abound, in many places, in remains of true Mammals. Yet not a trace of one has been found in the Cretaceous strata ; and this is true even in the Rocky Mountain region, where the strata are mostly of shallow-water origin, and partly of fresh-water formation. These last are examples, it is true, from terrestrial species. But the very long blank antecedent to the Marsupials and to the true Mammals may well suggest the pro-

priety of making further search before assuming that in the gradation upward there were no greater interruptions than are illustrated by the variations among existing Mammals.

In the case of Man, the abruptness of transition is still more wonderful. The Man-ape, nearest in structure to Man, has a cranium of but 34 cubic inches in capacity, or half that of the lowest of existing Man, and no link between has been found. No human remains that the past fifteen years of active search have brought to light afford evidence of the existence of a race less perfectly erect than existing Man, or nearer to the Man-ape in essential characteristics. The Man-apes of the present day, the Gorilla, Chimpanzee, and Orang-Utan, are the terminations of lines of succession that reached up to them. But, as to the line supposed to end in Man, not the first link has been found. Thus geological discovery leaves Man *alone* at the head of the system of life, far removed from his nearest allies among the brute races.

12. Origin of Species. — Such is the direct evidence from Geology as to the transitions between species. The other considerations, derived from Geology, that have been regarded as bearing on the question of the origin of species, are —

1. That the system of life exhibits so perfect harmony, and so complete oneness of law in its several lines and successions, that it may be truly called a system of development or evolution, whatever the method by which it was carried forward.

2. That since the physical progress of the globe was under the action of natural law, so the same may naturally have been true of its organic progress.

3. That, as regards geological history, *time is long*.

These arguments in themselves are an insufficient basis for a settlement of the great question.

Science derives other evidences from the study of *living* plants and animals; but this is not the place for their presentation. Still other arguments come from *a priori*, abstract, or metaphysical considerations, and these too would be here out of place.

The biblical student finds, in the first chapter of Genesis, positive statements with regard to the creation of living beings. But these statements are often misunderstood; for they really leave the question as to the operation of natural causes for the most part an open one, — as asserted by Augustine, among the Fathers of the Church, and by some biblical interpreters of the present day; for it says that there were but *four fiats* for the whole; or but *two*, excluding the first for the beginning of life, and the last for the creation of Man. And it plainly implies that, after the *fiats*, that is, through these expressions of the Divine Will, the new developments went forward successively to the completion of the grand system.

In view of the whole subject, the following appear to be the conclusions most likely to be sustained by further research.

1. The evolution of the system of life went forward through the derivation of species from species, according to natural methods not yet clearly understood, and with few occasions for supernatural intervention.

2. The method of evolution admitted of abrupt transitions between species; as has been argued from the abrupt transitions that occur in the development of animals that undergo metamorphosis, and the successive stages in the growth of many others.

3. External agencies or conditions, while capable of producing modifications of structure, have had no more power toward determining the directions of progress in the evolution, than they now have in determining the course of progress in development from a living germ.

4. For the development of Man, gifted with high reason and will, and thus made a power above Nature, there was required, as Wallace has urged, the special act of a Being above Nature, whose supreme will is not only the source of natural law, but the working force of Nature herself.

CONCLUDING REMARKS.

Geology may seem to be audacious in its attempts to unveil the mysteries of creation. Yet what it reveals are only some of the methods by which the Creator has performed his will; and many deeper mysteries it leaves untouched.

It brings to view a perfect and harmonious system of life, but affords no explanation of the origin of life, or of any of nature's forces.

It accounts for the forms of continents; but it tells nothing as to the source of that arrangement of the wide and narrow continents and wide and narrow oceans that was necessary to the grand result.

It teaches that strata were made in many successions as the continents lay balancing near the water's level, sometimes just above the surface, sometimes a little below; but it does not explain how it happened that the amount of water was of exactly the right quantity to fill the great basin, and admit of oscillations of the land beneath or above its surface by only *small* changes of level; for if the water had been a few hundred feet below the level it now has, the continents would have remained mostly without their marine strata, and the plan of progress would have proved a failure; or if as much above its present level, the land through the earlier ages would have been sunk to depths comparatively lifeless, with no less fatal results both to the series of rocks and the system of

marine and terrestrial life ; and in the end there would have been broad and narrow strips of dry land and archipelagoes, in place of the expanded Orient and Occident.

It may be said to have searched out the mode of development of a world. Yet it can point to no physical cause of that prophecy of Man which runs through the whole history ; which was uttered by the winds and waves at their work over the sands, by the rocks in each movement of the earth's crust, and by every living thing in the long succession, until Man appeared to make the mysterious announcements intelligible. For the body of Man was not made more completely for the service of the soul, than the earth, in all its arrangements from beginning to end, for the spiritual being that was to occupy it. In Man, the bones are not merely the jointed framework of an animal, but a framework shaped throughout with reference to that erect structure which befits and can best serve Man's spiritual nature. The feet are not the clasping and climbing feet of a monkey ; they are so made as to give firmness to the tread and dignity to the bearing of the being made in God's image. The hands have that fashioning of the palm, fingers, and thumb, and that delicacy of the sense of touch, which adapt them not only to feed the mouth, but to contribute to the wants of the soul and obey its promptings. The arms are not for strength alone, — for they are weaker than in many a brute, — but to give the greater power and expression to the thoughts that issue from within. The face, with its expressive features, is formed so as to respond not solely to the emotions of pleasure and pain, but to shades of sentiment and interacting sympathies the most varied, high as heaven and low as earth, — ay, lower, in debased human nature. And the whole being, body, limbs, and head, with eyes looking, not toward the earth, but beyond an infinite horizon, is a majestic expression of the divine feature in Man, and of the infinitude of his aspirations.

So with the earth, Man's world-body. Its rocks were so arranged, in their formation, that they should best serve Man's

purposes. The strata were subjected to metamorphism, and so crystallized that he might be provided with the most perfect material for his art, — his statues, temples, and dwellings; at the same time they were filled with veins, in order to supply him with gold and silver and other treasures. The rocks were also made to enclose abundant beds of coal and iron ore, that Man might have fuel for his hearths and iron for his utensils and machinery. Mountains were raised to temper hot climates, to diversify the earth's productiveness, and, pre-eminently, to gather the clouds into river-channels, thence to moisten the fields for agriculture, afford facilities for travel, and supply the world with springs and fountains.

The continents were clustered mostly in one hemisphere to bring the nations into closer union; and the two having climates and resources the best for human progress, — the northern Orient and Occident, — were separated by a *narrow* ocean, that the great mountains might be on the remoter borders of each, and all the declivities, plains, and rivers be turned toward one common channel of intercourse. So, also, the species of life, both of plants and animals, were appointed to administer to Man's necessities, moral as well as physical.

Besides these beneficent provisions, the forces and laws of nature were particularly adapted to Man, and Man to those laws, so that he should be able to take the oceans, rivers, and winds into his service, and even the more subtle agencies, heat, light, and electricity; and the adjustments were made with such precision that the face of the earth is actually fitted hardly less than his own to respond to his inner being: the mountains to his sense of the sublime, the landscape, with its slopes, its trees, its flowers, to his love of the beautiful, and the thousands of living species, in their diversity, to his various emotions and sentiments. The whole world, indeed, seems to have been made almost a material manifestation, in multitudinous forms, of the elements of his own spiritual nature, that it might thereby give wings to the soul in its heavenward aspirings. It may therefore be said with truth that Man's

spirit was considered in the ordering of the earth's structure as well as in that of his own body.

It is hence obvious that the earth's history, which it is the object of Geology to teach, is the true introduction to human history.

It is also certain that science, whatever it may accomplish in the discovery of causes or methods of progress, can take no steps toward setting aside a Creator. Far from such a result, it clearly proves that there has been not only an omnipotent hand to create, and to sustain physical forces in action, but an all-wise and beneficent Spirit to shape all events toward a spiritual end.

Man may well feel exalted to find that he was the final purpose when the word went forth in the beginning, LET LIGHT BE. And he may thence derive direct personal assurance that all this magnificent preparation is yet to have a higher fulfilment in a future of spiritual life. This assurance from nature may seem feeble. Yet it is at least sufficient to strengthen faith in that Book of books in which the promise of that life and "the way" are plainly set forth.

APPENDIX.

A.—Map of the Vicinity of Naples.

THE accompanying map serves to illustrate the sketch on page 130. It covers in breadth just 20 miles. It shows the position of Vesuvius; its cone and crater; the cinder-cone within the crater; and the outer margin (called *Somma*, on



the north) of a larger cone and crater,—probably that of A.D. 79, previous to the eruption which destroyed Pompeii. The crater, after some of its eruptions, has been 2000 feet deep; at other times it has within a solid lava-plain near its top, and a cinder-cone at centre, which was the case at the time of the author's visit in June, 1834. To the southeast of Vesuvius lies Pompeii, tufa-covered; and west of it, on the coast, Herculaneum, beneath tufa of the year 79, the lavas of six subsequent eruptions separated by thin layers of soil, and the cities of Resina and Portici. West of Naples,

Lake d'Agnano occupies the crater of a volcano; the Solfatara, an area now of steaming fissures, with sulphurous and other vapors, another; and Astroni is a volcanic cone made of tufa. Pozzuoli, with the Temple of Serapis, whose few standing columns bear evidence of great changes of level in the land, occupies a point just west of the limits of the map; and north of it are the volcanic cones of Monte Nuovo (thrown up in 1538) and Monte Barbaro, of unknown date.

B.—Catalogue of American Localities of Fossils.

THE following catalogue of American localities of fossils contains only some of the more important, and is intended for the convenience especially of the student-collector.

Localities of Fossils.

Acadian Group.—Coldbrook, Ratcliffe's Millstream, St. John, New Brunswick. — Long Arm of Canada Bay, Newfoundland.

Potsdam Group.—Swanton, Vt. — Braintree, Mass. — Keeseville (at "High Bridge"), Alexandria, Troy, N. Y. — Chiques Ridge, Pa. — Falls of St. Croix, Osceola Mills, Trempaleau, Wisconsin. — Lansing, Iowa. — St. Ann's, Isle Perrot, C. W. — Near Beauharnois on Lake St. Louis, C. E.

Calciferosus.—Mingan Islands, St. Timothy, and near Beauharnois, C. E. — Grand Trunk Railway between Brockville and Prescott, St. Ann's, Isle Perrot, C. W. — Amsterdam, Fort Plain, Canajoharie, Chazy, Lafargeville, Ogdensburg, N. Y.

Quebec Group.—Mingan Islands, Point Levi, Philipsburg, and near Beauharnois, C. E. — Point Rich, Cow Head, Newfoundland. — Cuts in Black Oak Ridge and Copper Ridge, Knoxville and Ohio Railroad, Tenn. — Malade City, Idaho.

Chazy Limestone.—Chazy, Galway, Westport, N. Y. — One to three miles north of "the Mountain" Island of Montreal, C. E. — St. Joseph's Island, Sault Ste. Marie, C. W. — Knoxville, Lenoir's, Bull's Gap, Kingsport, Tenn.

Bird's-eye Limestone.—Amsterdam, Little Falls, Fort Plain, Adams, Watertown, N. Y.

Black River Limestone.—Watertown, N. Y. — Ottawa, C. W. — Island of Montreal, and near Quebec, C. E.

Trenton Limestone.—Adams, Watertown, Boonville, Turin, Jacksonburg, Little Falls, Lowville, Middleville, Fort Plain, Trenton Falls, N. Y. — Pine Grove, Aaronsburg, Potter's Fort, Milligan's Cove, Pa. — Highgate

Spring, Vt. — Montmorency Falls and Beauport Quarries near Quebec, Island of Montreal (quarries north of the city), C. E. — **Ottawa, Belleville, Trenton** (G. T. R. R., west of Kingston), C. W. — **Copper Bay, Mich.** — Elkader Mills, Turkey River, Dubuque, Iowa. — **Falls of St. Anthony, St. Paul, Mineral Point, Cassville, Beloit, Quimby's Mills near Benton, Wis.** — **Warren, Rockton, Winslow, Dixon, Freeport, Cedarville, Savanna, Rockford, Ill.** — Murfreesborough, Columbia, Lebanon, Tenn.

Utica Slate. — Turin, Martinsburg, Lorraine, Worth, Utica, Cold Spring, Oxtungo and Osquago Creeks near Fort Plain, Mohawk, Rouse's Point, N. Y. — Rideau River along railroad at Ottawa, bed of river two miles above, C. W.

Cincinnati Group. — Pulaski, Rome, Lorraine, Boonville, N. Y. — Penn's Valley, Milligan's Cove, Pa. — Oxford, Cincinnati, Lebanon, O. — Madison, Richmond, Ind. — Anticosti, opposite Three Rivers, C. E. — Weston on the Humber River, nine miles west of Toronto, C. W. — Little Makoqueta River, Iowa. — Savannah, Green Bay, Wis. — Thebes, Alexander County; Savanna, Carroll County; Scales's Mound, Jo Daviess County; Oswego, Yorkville, Kendall County; Naperville, Dupage County; Wilmington, Will County, Ill. — Cape Girardeau, Mo. — Drummond's Island, Mich. — Nashville, Columbia, Knoxville, Tenn.

Medina Sandstone. — Lockport, Lewiston, Medina, Rochester, N. Y. — Long Narrows below Lewistown, Pa. — Dundas, C. W.

Clinton Group. — Lewiston, Lockport, Reynolds Basin, Brockport, Rochester, Wolcott, New Hartford, N. Y. — Thorold on Welland Canal, Hamilton, Ancaster, Dundas, C. W. — Hanover, Ind.

Niagara. — Lewiston, Lockport, Gosport, Rochester, Wolcott, N. Y. — Thorold, Hamilton, Ancaster, C. W. — Anticosti, C. E. — Arisaig, Nova Scotia. — Racine, Waukesha, Wis. — Sterling, Grafton, Savanna, Chicago, Joliet, Ill. — Marblehead on Drummond's Island, Michigan. — Springfield, Cedarville, Ohio. — Delphi, Waldron, Jeffersonville, Madison, Logansport, Peru, Ind. — Louisville, Ky. — The "glades" of West Tennessee. (**Coral-line Limestone.** — Schoharie, N. Y.)

Onondaga Salt Group. — Buffalo, Williamsville, Waterville, Jerusalem Hill (Herkimer County), N. Y. — Galt, Guelph (G. T. R. R.), C. W.

Lower Helderberg Limestones. — Dry Hill, Jerusalem Hill (Herkimer County), Sharon, East Cobleskill, Judd's Falls, Cherry Valley, Carlisle, Schoharie, Clarksville, Athens, N. Y. — Pembroke, Parlin Pond, Me. — Gaspé, C. E. — Arisaig, East River, Nova Scotia. — Peach Point, opposite Gibraltar, Ohio. — Thebes, Devil's Backbone, Ill. — Bailey's Landing, Mo. — "Glades" of Wayne and Hardin Counties, Tenn.

Oriskany Sandstone. — Oriskany, Vienna, Carlisle, Schoharie, Pucker Street, Catskill Mountains, N. Y. — Cumberland, Md. — Moorestown and Frankstown, Pa. — Bald Bluffs, Jackson County, Ill. — Four miles S. W. of St. Mary's, Ste. Genevieve County, Mo.

Cauda-galli Grit. — Schoharie (*Fucoides Cauda-galli*), N. Y.

Schoharie Grit. — Schoharie, Cherry Valley, N. Y.

Upper Helderberg Limestones. — Black Rock, Buffalo, Williamsville,

Lancaster, Clarence Hollow, Stafford, Le Roy, Caledonia, Mendon, Auburn, Onondaga, Cassville, Babcock's Hill, Schoharie, Cherry Valley, Clarksville, N. Y. — Port Colborne, and near Cayuga, C. W. — Columbus, Delaware, White Sulphur Springs, Sandusky, Ohio. — Mackinac, Little Traverse Bay, Dundee, Monguagon, Mich. — North Vernon, Charlestown, Kent, Hanover, Jeffersonville, Ind. — Louisville, Ky.

Marcellus Shales. — Lake Erie shore, ten miles S. of Buffalo, Lancaster, Alden, Avon, Leroy, Marcellus, Manlius, Cherry Valley, N. Y.

Hamilton Group. — Lake Erie shore, Eighteen Mile Creek, Hamburg, Alden, Darien, York, Moscow, East Bethany, Bloomfield, Bristol, Seneca Lake, Cayuga Lake, Skaneateles Lake, Moravia, Pompey, Cazenovia, Delphi, Bridgewater, Richland, Cherry Valley, Seward, Westford, Milford, Portlandville, N. Y. — Widder Station (G. T. R. R.), near Port Sarnia, C. W. — New Buffalo, Independence, Rockford, Iowa. — Devil's Bake Oven, Jackson County, Moline, Rock Island, Ill. — Grand Tower, Mo. — Thunder Bay, Little Traverse Bay, Mich. — Jeffersonville, Ind. — Nictaux, Bear River, Moose River, Nova Scotia.

Genesee Shale. — Banks of Seneca and Cayuga Lakes, Lodi Falls, Mount Morris, two miles south of Big Stream Point, Yates County, N. Y. — (**Genesee or Portage**. — Delaware, Ohio. — Rockford, North Vernon, Ind. — Danville, Ky.)

Portage Group. — Eighteen Mile Creek on Lake Erie, Chautauqua Lake, Genesee River at Portage, Flint Creek, Cashaqua Creek, Nunda, Seneca and Cayuga Lakes, N. Y.

Chemung Group. — Rockville, Philipsburg, Jasper, Greene, Chemung Narrows, Troopsville, Elmira, Ithaca, Waverly, Hector, Enfield, Franklin, N. Y. — Gaspé, C. E.

Catskill Group. — Fossils rare. — Richmond's quarry above Mount Upton on the Unadilla, Oneonta, Oxford, Steuben County, south of the Canisteo, N. Y.

Subcarboniferous. — Burlington, Keokuk, Columbus, Iowa. — Quincy, Warsaw, Alton, Kaskaskia, Chester, Ill. — Crawfordsville, Greencastle, Bloomington, Spergen Hill, New Providence, Ind. — Hannibal, St. Genevieve, St. Louis, Mo. — Willow Creek, Battle Creek, Marshal, Moscow, Jonesville, Holland, Grand Rapids, Mich. — Mauch Chunk, Pa. — Newtonville, Ohio. — Ice's Ferry, on Cheat River, Monongalia County, W. Va. — Red Sulphur Springs, Pittsburg Landing, White's Creek Springs, Waynesville, Cowan, Tenn. — Big Bear and Little Bear Creeks, Big Crippled Deer Creek, Miss. — Clarksville, Huntsville, Ala. — Windsor, Horton, Nova Scotia.

Carboniferous. — South Joggins, Pictou, Sydney, Nova Scotia. — Wilkesbarre, Shamokin, Tamaqua, Pottsville, Minersville, Tremont, Greensburg, Carbondale, Port Carbon, Lehigh, Trevorton, Johnstown, Pittsburg, Pa. — Pomeroy, Marietta, Zanesville, Cuyahoga Falls, Athens, Yellow Creek, Ohio. — Charlestown, Clarksburg, Kanawha, Salines, Wheeling, W. Va. — Saline Company's Mines, Gallatin County; Carlinville, Hodges Creek, Macoupin County; Colchester, McDonough County; Duquoin, Perry County; Mur-

physborough, Jackson County ; Lasalle ; Morris, Mazon, and Waupecan Creeks, Grundy County ; Danville, Pettys' Ford, Vermilion County ; Paris, Edgar County ; Springfield, Ill. — Perrysville, Eugene, Newport, Horseshoe of Little Vermillion, Vermillion County ; Durkee's Ferry, near Terre Haute, Vigo County ; Lodi, Parke County ; Merom, Sullivan County, Ind. — Bell's, Casey's, and Union Mines, Crittenden County ; Hawesville and Lewisport, Hancock County ; Breckenridge, Giger's Hill, Mulford's Mines, and Thompson's Mine, Union County ; Providence and Madisonville, Hopkin's County ; Bonharbour, Daviess County, Ky. — Muscatine, Alpine Dam, Iowa. — Leavenworth, Indian Creek, Grasshopper Creek, Juniata, Manhattan, Kansas. — Rockwood, Emory Mines, Coal Creek, Careyville, Tenn. — Tuscaloosa, Ala.

Triassic. — Southbury, Middlefield, Portland, Conn. — Turner's Falls, Sunderland, Mass. — Phoenixville, Pa. — Richmond, Va. — Deep River and Dan River Coal-fields, N. C.

Cretaceous. — Upper Freehold, Middletown, Marlborough, Blue Ball, Monmouth County ; Pemberton, Vincenton, Burlington County ; Blackwoodtown, Camden County ; Mullica Hill, Gloucester County ; Woodstown, Mannington, Salem County ; New Egypt, Ocean County, N. J. — Warren's Mill, Itawamba County ; Tishomingo Creek, R. R. cuts, Hare's Mill, Carrollsville, Tishomingo County ; Plymouth Bluff, Lowndes County ; Chawalla Station (M. & C. R. R.), Ripley, Tippah County ; Noxubee, Macon, Noxubee County ; Kemper, Pontotoc and Chickasaw Counties, Miss. — Finch's Ferry, Prairie Bluff, on Alabama River ; Choctaw Bluff, on Black Warrior River ; Greene, Marengo, and Lowndes Counties, Ala. — Fox Hills, Sage Creek, Long Lake, Great Bend, Cheyenne River, etc., Nebraska. — Fort Harker, Fort Hayes, Fort Wallace, Kansas. — Fort Lyon, Santa Fé, New Mexico.

Eocene. — Everywhere in Tippah County ; Yockene River ; New Prospect P. O., Winston County ; Marion, Lauderdale County ; Enterprise, Clarke County ; Jackson, Sartatia, Yazoo County ; Homewood, Scott County ; Chickasawhay River, Clarke County ; Winchester, Red Bluff Station, Wayne County ; Vicksburg, Amsterdam, Brownsville, Warren County ; Brandon, Byram Station, Rankin County ; Paulding, Jasper County, Miss. — Claiborne, Monroe County ; St. Stephen's, Washington County, Ala. — Charleston, S. C. — Tampa Bay, Florida. — Fort Washington, Fort Marlborough, Piscataway, Md. — Marlbourne, Va. — Brandon, Vt. — In New Jersey, at Farmingdale, Squankum and Shark River, Monmouth Co. — Green River, Fort Bridger, Wyoming. — Cañada de las Uvas, Cal.

Miocene. — Gay Head, Martha's Vineyard, Mass. — Shiloh, Jericho, Cumberland County, and Deal, Monmouth County, N. J. — St. Mary's, Easton, Md. — Yorktown, Suffolk, Smithfield, Richmond, Petersburg, Va. — Astoria, Willamette Valley, John Day Valley, Oregon. — San Pablo Bay, Ocoya Creek, San Diego, Monterey, San Joaquin and Tulare Valleys, Cal. — White River, Upper Missouri Region. — Crow Creek, Colorado.

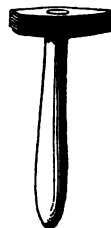
Pliocene. — Ashley and Santee Rivers, S. C. — Platte and Niobrara Rivers, Upper Missouri. — John Day Valley, Oregon. — Sinker Creek, Idaho. — Alameda County, Cal.

C.—Geological Implements, Specimens, etc.

1. **Implements.**—The student requires for his geological excursions and research the following implements :—

(1.) A *hammer*. If his object is to get specimens of hard rocks, or obtain minerals from such rocks, it should have the form in Fig. 459, the edge being in the direction of the handle. But if fossils are to be collected, this edge should be transverse to the handle. The face should be flat, and nearly square, with its edges sharp instead of rounded. The socket for the handle should be large, that the handle may be strong. The hammer, for ordinary excursions, should weigh $1\frac{1}{2}$ pounds exclusive of the handle ; the handle should be about 12 inches long. Another is required for trimming specimens, weighing half a pound.

Fig. 459.



(2.) A *steel chisel*, 6 inches long, such as is used by stone-cutters. Also, another half this size.

(3.) A *clinometer*, with *magnetic needle* attached. The best kind is a clinometer-compass 3 inches in diameter, *having a square base* about $3\frac{1}{2}$ inches each side, two sides of the base being parallel to the north and south line of the compass.

(4.) A *small magnet*. A magnetized blade of a pocket-knife is a good substitute.

(5.) A *measuring-tape* 50 feet long. The field geologist should know accurately the measurements of his own body, his height, length of limbs, step or pace, that he may use himself, whenever needed, as a measuring-rod.

(6.) In many cases, a *pick*, a *crow-bar*, a *sledge-hammer* of 4 to 8 pounds' weight, and the means of blasting, are necessary.

(7.) Besides the above, a *barometer* and *surveyor's instruments* are occasionally required. Of the latter, a *hand-level* is a desirable instrument for determining small elevations by levelling ; it is a simple brass tube, with cross-hairs, bubble, and mirror. A first-rate *aneroid barometer* is excellent for all heights between 5 feet and 2,000 feet ; and, having one, the *hand-level* is superfluous.

2. **Specimens.**—Specimens for illustrating the kinds of rocks should be carefully trimmed by chipping to a uniform size, previously determined upon : 3 inches by 4 across, and 1 inch through, is the size commonly adopted. In the best collections of rocks, the angles are squared and the edges made straight with great precision. They should have a fresh surface of fracture, with no bruises by the hammer. It is often well to leave one side in its natural weathered state, to show the effects of weathering.

Specimens of fossils will, of course, vary in size with the nature

of the fossil. When possible, the fossil should be separated from the rock ; but this must be done with precaution, lest it be broken in the process ; it should not be attempted unless the chances are strongly in favor of securing the specimen entire. The skilful use of a small chisel and hammer will often expose to view nearly all of a fossil when it is not best wholly to detach it. When the fossils in a limestone are silicified (a fact easily proved by their scratching glass readily and their undergoing no change in heated acid), they may be cleaned by putting them into an acid, and also applying heat very gently, if effervescence does not take place without it. The best acid is chlorohydric (muriatic) diluted one half with water.

Collections both of rocks and fossils should always be made from rocks *in place*, and not from stray boulders of uncertain origin.

3. Packing. — For packing, each specimen should be enveloped separately in two or three thicknesses of strong wrapping-paper. This is best done by cutting the paper of such a size that when folded around the specimen the ends will project two inches (more or less, according to the size of the specimen) ; after folding the paper around it, turn in the projecting ends (as the end of the finger of a glove may be turned in), and the envelope will need no other securing. Pack in a strong box, pressing each specimen, after thus enveloping it, firmly into its place, crowding wads of paper between them wherever possible, and make the box absolutely full to the very top (by packing-material if the specimens do not suffice), so that no amount of rough usage by wagon or cars on a journey of a thousand miles would cause the least movement inside.

4. Labelling. — A *label* should be put inside of each envelope, separated from the specimen by a thickness or more of the paper. The label should give the precise locality of the specimen, and the particular stratum from which taken, if there is a series of strata at the place ; it should also have a number on it corresponding to a number in a note-book, where fuller notes of each are kept, together with the details of stratification, strike, and dip, sections, plans, changes or variations in the rocks, and all geological observations that may be made in the region. A specimen of rock or fossil of unknown or uncertain locality is of very little value.

D.—List of Minerals and Rocks.

The minerals and rocks enumerated below are those of highest importance to the geological student. The list of minerals includes 100 specimens; that of rocks, 70. Good collections containing the 170 specimens numbered as below and labeled can be purchased for twenty to twenty-five dollars; and all schools and academies in which the subject is taught should be provided with one. The order in the following list of minerals is that of the author's small Manual of Mineralogy.

Minerals.

- | | |
|--|--|
| 1. Native Sulphur. | 18. Gypsum (Hydrous calcium sulphate): <i>a</i> , selenite; <i>b</i> , massive earthy. |
| 2. Graphite. | 19. Apatite (Calcium phosphate). |
| 3. Native Copper. | 20. Guano: <i>a</i> , <i>b</i> , two varieties. |
| 4. Chalcopyrite (Copper pyrites). | 21. Calcite (Calcium carbonate): <i>a</i> , cleavage rhombohedron; <i>b</i> , crystalline; <i>c</i> , travertine; <i>d</i> , stalactite; <i>e</i> , stalagmite. |
| 5. Malachite (Copper carbonate). | 22. Dolomite (Magnesian calcium carbonate). |
| 6. Galenite (Lead sulphide); <i>a</i> , coarsely crystallized; <i>b</i> , fine granular. | 23. Barite (Barium sulphate). |
| 7. Sphalerite (Zinc blende); <i>a</i> , brown or yellow; <i>b</i> , black. | 24. Quartz: <i>a</i> , crystals; <i>b</i> , group of crystals or drusy quartz; <i>c</i> , massive glassy; <i>d</i> , smoky; <i>e</i> , opaque, pebbles, <i>f</i> , flint, hornstone, or chert; <i>g</i> , jasper; <i>h</i> , chalcedony. |
| 8. Calamine (Zinc silicate). | 25. Opal: <i>a</i> , common; <i>b</i> , infusorial earth (Diatom earth, electrosilicon of the shops). |
| 9. Cassiterite (Tin ore). | 26. Pyroxene: <i>a</i> , black or greenish-black crystals in a volcanic rock; <i>b</i> , green pyroxene. |
| 10. Pyrite (Iron disulphide): <i>a</i> , cubes; <i>b</i> , massive; <i>c</i> , decomposing and having a copperas-like taste. | 27. Amphibole: <i>a</i> , <i>b</i> , hornblende, black, and greenish-black; <i>c</i> , actinolite, green; <i>d</i> , tremolite, white; <i>e</i> , asbestos. |
| 11. Pyrrhotite (Iron sulphide). | 28. Beryl. |
| 12. Hematite (Iron sesquioxide): <i>a</i> , crystallized; <i>b</i> , massive; <i>c</i> , earthy red oxide or ochre. | 29. Chrysolite. |
| 13. Magnetite (Magnetic iron ore): <i>a</i> , octahedral crystals; <i>b</i> , granular massive. | 30. Garnet: <i>a</i> , dodecahedral crystal; <i>b</i> , trapezohedral or dodecahedral crystals in the rock. |
| 14. Limonite (Hydrous iron-sesquioxide, Brown hematite): <i>a</i> , botryoidal or stalactitic; <i>b</i> , earthy or yellow ochre; <i>c</i> , bog iron ore. | 31. Zircon: 2 crystals. |
| 15. Siderite (Iron carbonate): <i>a</i> , light gray; <i>b</i> , dark brown from partial alteration toward limonite. | 32. Epidote. |
| 16. Manganese oxide, either Pyrolusite or Psilomelane. | |
| 17. Corundum (Alumina, Al_2O_3). | |
| 18. Fluorite (Fluor Spar, Calcium fluoride): <i>a</i> , crystal; <i>b</i> , massive. | |

- 33, 34. The *Micas*. — 33, Muscovite : *a*, *b*, two varieties ; 34, Biotite.
 35. Scapolite.
 36–39. The *Feldspars*. — 36, Labradorite ; 37, Oligoclase ; 38, Albite ; 39, Orthoclase ; *a*, white ; *b*, flesh-colored.
 40. Chondrodite.
 41. Tourmaline : *a*, black crystal ; *b*, specimen in the rock.
 42. Andalusite : chiastolite in slate.
 43. Cyanite.
 44. Staurolite : 2 specimens.
45. Talc : *a*, foliated ; *b*, steatite (soap-stone).
 46. Glauconite (Green earth).
 47. Serpentine : *a*, light green ; *b*, dark.
 48. Kaolinite (Kaolin).
 49. Chlorite : massive granular.
 50. Bitumen.
 51. Mineral coal : *a*, anthracite ; *b*, bituminous coal ; *c*, cannel coal ; *d*, brown coal ; *e*, lignite.
 52. Peat : *a*, imperfectly changed ; *b*, good peat ; *c*, muck.

Rocks.

1. *Fragmental non-calcareous*.
 1. Sand : *a*, ordinary of seashore ; *b*, magnetic iron sand with garnet sand, from seashore.
 2. Clay : *a*, common brick-clay (burns red) ; *b*, Fire-brick or Potters' clay (burns white).
 3. Sandstone : *a*, white or grayish ; *b*, red ; *c*, brown ; *d*, granitic ; *e*, laminated argillaceous (flagging stone) ; *f*, micaceous.
 4. Conglomerate : *a*, ordinary ; *b*, grit ; *c*, calcareous.
 5. Shale : *a*, gray or reddish ; *b*, carbonaceous (black).
 6. Tufa (volcanic sandstone or conglomerate).
2. *Metamorphic Rocks*.
 7. Granite : *a*, light gray ; *b*, flesh-colored, not coarse ; *c*, coarse vein granite ; *d*, porphyritic ; *e*, a granite with outer part rusted from partial decomposition.
 8. Gneiss : *a*, *b*, two varieties.
 9. Mica schist : *a*, *b*, two varieties ; *c*, garnetiferous.
 10. Hydromica schist : *a*, *b*, ordinary varieties.
 11. Chlorite schist.
 12. Argillite (Roofing slate) : *a*, dark gray or blackish ; *b*, red.
 13. Syenite or Quartz-Syenite.
 14. Syenite-gneiss (Hornblende gneiss).
 15. Hornblende schist.
 16. Dioryte.
 17. Labradyoryte.
 18. Quartzyte.
 19. Buhrstone.
3. *Calcareous Rocks*.
 20. Limestone ; A, *Uncrystalline* : *a*, common (better if fossiliferous) ; *b*, black ; *c*, light colored ; *d*, hydraulic ; *e*, chalk ; *f*, shell limestone (from St. Augustine, Florida) ; B, *Crystalline or metamorphic* : White marble ; *g*, gray or clouded ; *h*, reddish or brownish, (partially metamorphic of Tennessee, which contains fossil corals of the *Chætetes* group).
 21. Dolomite (Magnesian limestone) ; *a*, uncrystalline ; *b*, crystalline, white marble.
 22. Verd-antique marble.
4. *Igneous Rocks*.
 23. Doleryte : *a*, compact from Eastern America Triassic areas (Diabase) ; *b*, same, hydrous or chloritic ; *c*, amygdaloidal ; *d*, from modern eruptions ; *e*, doleritic, or ordinary lava ; *f*, scoriaceous.
 24. Peridotite (Chrysolithic doleryte, Basalt).
 25. Trachyte : *a*, ordinary ; *b*, pumice.
 26. Felsyte : *a*, light gray or whitish ; *a*, red porphyry.
 27. Pitchstone or Pearlstone.
 28. Obsidian.
30. Concretions : *a*, *b*, *c*, claystones, one of them spherical ; *d*, oolite.
 31. Geode : 2 specimens.
 32. Silicified wood : 2 specimens.
 33. Silicified fossils in limestone.

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